PROJECT REPORT[*]

Protecting Puget Sound Watersheds from Agricultural Pollution Using a Progressive Manure Application Risk Management (ARM) System

FINAL

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Prepared by:

Nichole Embertson, Ph.D.

Whatcom Conservation District

[*] This is a project report prepared for the EPA as part of a grant. This is not a peer reviewed referenceable document.

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4. PROJECT CONTACT

The Whatcom Conservation District was responsible for the development, implementation, and monitoring of the ARM project. The granting agency, US EPA Region 10, was responsible for the successful oversight and support for the ARM project.

For questions about the project and/or this report, please contact:

Nichole M. Embertson, Ph.D.
Project Manager and Lead Scientist
Whatcom Conservation District
6975 Hannegan Rd, Lynden, WA 98264
(360) 526-2381 x 126

For questions related to the EPA grant, please contact:

Jill Fullagar
Impaired Waters Coordinator
Watershed Unit, Office of Water and Watersheds
US EPA, Region 10
1200 Sixth Avenue, Suite 900 (OWW-192)
Seattle, WA 98101-3140
(206) 553-2582

5. EXECUTIVE SUMMARY

Throughout the Puget Sound region of Northwest Washington, impacted and poorly managed agriculture has repeatedly been advanced as a leading contributor to surface and ground water pollution, particularly during the winter months. Improvements in field application methods using the NRCS "4R's" method of nutrient management (right: rate, timing, source, and placement), are necessary in order to protect important resources from further negative impacts. This study aimed to develop an innovative Application Risk Management (ARM) System that focusing on the timing of manure application and targeted the transport of manure nutrients (N, P) and fecal coliform (FC) via runoff and leaching by promoting science-based, real-time assessment tools linked to measurable outcomes.

This study was conducted over 5 years from 2010-2015 in Whatcom County, WA. The project had three main components; field data collection, tool development, and education outreach. The strength of the project came from the implementation of a vigorous field sampling campaign conducted on six plots in Whatcom County looking at two manure application treatments to forage fields: 1) conventional (CON) manure application based on set dates as dictated by local ordinance and practice (February 15-October 31), and 2) strategic manure application based on a comprehensive Application Risk Management (ARM) system using real-time field and weather information and decision making tools.

To compare the two application treatments, a variety of field measurements were conducted looking at the movement of nutrients such as nitrogen and phosphorous, as well as other important parameters within the system. Sampling of vadose zone soil water was conducted based on storm events using 12 gravitational lysimeters placed at 12, 24, and 36 inches below the soil surface at random locations within each sample field. Soil samples were taken one to two times monthly at the same depths and locations as lysimeters for comparison and assessed for moisture and nutrients. Groundwater monitoring wells were also installed and sampled at the top of the water table and below to illustrate nutrient losses below the vadose zone and background (This work was conducted by USGS in a concurrent study. See their project report for more detail and results). In addition, surface water was sampled in-stream around storm events; manure nutrient and application rate was sampled at application events; forage was sampled for yield and quality at each cutting; and meteorological (i.e., precipitation, temperature, etc.) and management parameters were collected daily. All samples were analyzed by an accredited laboratory and data statistically analyzed for patterns and significance using the appropriate model in Excel or R (version 3.1.2).

All of the collected data was used to create and proof a real-time, easy to use Application Risk Management (ARM) worksheet that evaluated the risk of manure application to a specific field on a specific day and returned a runoff risk rating for manure application. A real-time Manure Spreading Advisory (MSA) was also created that provides a three day risk rating for runoff based on precipitation, field conditions, and protective measures in place. The MSA is a color coded map that is automatically updated daily using precipitation forecast data from NOAA. Support tools developed include a dedicated website for the ARM tools and nutrient management information (www.wadairyplan.org), dynamic manure application setback distances, and a field level risk mapping process that allows a user to select the lowest risk fields for runoff or leaching to apply to at any time of the year.

Results showed that strategic manure application timing and practices significantly reduced the potential for leaching and runoff events. The use of the Manure Spreading Advisory coupled with the Application Risk Management worksheet helped producers select low risk dates for application and prevented manure applications that would have otherwise occurred at times when large rain events could have caused pollution events. By utilizing the customized ARM manure application strategy that encouraged applications be tailored to soil type and account for current field and weather conditions, a significant reduction in nitrate leaching and runoff potential was realized as compared to “conventional” application practices that do not account for these parameters. Additionally, field trials showed an increase in early season forage production with the ARM strategy, thus adding value to producers through production benefits. Coupled with targeted outreach opportunities, adoption of this ARM program was well received by producers.

6. A NOTE FROM THE PROJECT MANAGER

The following final project report is a recount of the process and results of five years of study and work. The project was originally planned for four years from 2010-2014, but due to negotiations the first year, work was delayed and therefore a no-cost extension was requested and granted, stretching the project into 2015. Due to the overwhelming volume of data, the project report is being submitted as allowed in 2016.

The project described herein is slightly different from the original proposal and quality assurance project plan (QAPP). Most notably, the number and complexity of sites was reduced to allow for a more thorough investigation. Only one site was included that had surface water adjacent, and it was added later in the project (2013). This means that there is little surface water data or results presented. This did not hinder the creation of the runoff advisory, nor its validation of relevant parameters. However, it does provide an area that more exploration and investigation is needed in future projects.

This project has been successful in raising a significant number of questions, interest, and areas that need additional work. It has also been invaluable in identifying future research needs and providing real-time decision making tools for farmers. Additionally, various aspects of the project have been leveraged into three new grant projects all looking at expanding and/or improving our knowledge of agricultural impacts to natural resources within the Puget Sound and beyond.

Because of the dynamic nature of the tools developed and the new information and science becoming available, the information and tools associated with this project will continue to be improved and updated. Therefore, the information presented within may not be entirely representative of the current products.

Note that while data have been statistically assessed, this is not a peer-reviewed paper. The data presented within should be used in context and understood before making conclusions. All landowners acted in cooperation with the Whatcom Conservation District on project treatments, activities, and coordination.

7. ABSTRACT

Impacted and poorly managed agriculture has been advanced as a leading contributor to surface and ground water pollution. Improvements in manure application methods and tools are necessary to further protect resources. This study developed an innovative Application Risk Management (ARM) System targeting the transport of manure pathogens and nutrients (N, P) via runoff and leaching by using validated real-time assessment tools. The study was conducted on dairy forage fields from 2010-15 in Whatcom County, WA. A vigorous sampling campaign was conducted on 6 plots comparing conventional manure application strategies to strategic application using a real-time ARM system developed by this project. Soil water was sampled at storm events using 6 gravitational lysimeters placed at 12, 24 and 36 in below the soil surface at random locations within each plot. Co-located groundwater monitoring wells were sampled monthly at water table and background (USGS). Soil samples were taken 1-2 times monthly at same depths and locations. In addition, surface water was sampled in-stream at storm events; manure was sampled at each application; forage was sampled at each cutting; and meteorological and management parameters were collected daily. Data was used to create and proof a web-based, easy to use worksheet that farmers use to evaluate manure application runoff risk on a specific field and day using real-time forecast, soil and field parameters. A Manure Spreading Advisory (MSA) was developed to provide a three day risk rating map for runoff based on precipitation forecast. Support tools included a website, dynamic manure application setback distances, and field level risk mapping. The ARM system provided flexibility and accountability to farmers for maximizing crop production and protecting water quality.

8. INTRODUCTION / BACKGROUND

Of the 12 Washington State Puget Sound Districts, Whatcom County has the greatest concentration of dairy cows, with 53% of the total, or over 45,562 animals (USDA, 2012), within its boundaries, most (~75%) of which are concentrated in the 310 mi^2 of the Nooksack and Strait of Georgia watersheds. Although the number of dairy farms in Whatcom has decreased by half in the last 10 years, the number of milk cows has only been reduced by about 30%, putting increased pressure on available land and water resources.

The combined Nooksack and Strait of Georgia watershed areas are under both land use change and environmental resource pollution strain. The primary resources and industries affected by these pressures are agriculture (primarily dairy), shellfish and salmonid fish populations, as well as the surface and ground water quality that supports these industries and the populations that surround them.

Due to land use changes and population pressures, the Lower Nooksack Sub-basin has a heavily impacted floodplain, high nitrates in groundwater, elevated fecal coliform levels in surface waters, and poor riparian conditions throughout the Nooksack River and most of its tributaries. Department of Ecology's (Ecology) current (2012) 303(d) list of impaired waters shows that there are 34 stream and river segments in the watershed that are above acceptable limits for, among other things, fecal coliform. The Ecology Nooksack River Watershed TMDL (Hood, 2002) plan lists the improper application of manure to agricultural fields as a potential, significant source of fecal coliform to the watershed. The discharge of fecal coliform into local harbors and bays has led to a significant history of shellfish bed closures and reopenings, which has had a detrimental effect to Tribes and commercial harvesters.

Poor water quality, coupled with the loss of stream habitat, has contributed to the noticeable decrease in annual salmon populations returning to the watershed (Ruckelshaus et al., 2002). This impacts Tribal communities as well as local industries, and threatens the future health of the salmon population in the area. Additionally, compared to other rivers in the Puget Sound region, the Nooksack River near its mouth at Portage Bay has among the highest levels of nitrogen, phosphorous, and suspended solids, which affects both upstream fish and shellfish populations in adjacent marine waters.

In Whatcom County, as in many other counties in the State, impacted and poorly managed agriculture (in particular, manure application) has repeatedly been advanced as a leading contributor to water pollution in watersheds. Therefore, the most productive way to address many of the water pollution issues within the watershed, and contribute to the larger interconnected effort of protection of the watershed, is to target improvement of the application of manure to farm fields. Improper application of manure can lead to runoff and/or leaching events, which can adversely impact water bodies with nutrients and pathogens. Since dairies are the largest producers of manure and manure application in the watershed, improvements in field application methods and timing can have a large impact in protecting watershed resources from further negative impacts.

However, current guidelines do not promote better application practices, and in fact, threaten the health of the Sound even further by fostering application under risky conditions and times of the year (October and February) without proper assessment of weather or field conditions. Following 1998 Dairy Nutrient Management Plan (DNMP) Guidance and the Whatcom County "Manure and Agricultural Nutrient Management" Ordinance (16.28), the historical manure application guidance for Whatcom County has been: ceasing of manure application on October 15th in the floodplain and October 31st everywhere else, and starting of application in the spring at T-Sum200 (200 cumulative celcius temperature units after Jan 1) or February 15, regardless of current field and weather conditions. The dates are estimated values chosen to coincide with the start of flood/rain season and plant growth, respectively, but in a changing climate and impacted resources concerns, are not always accurate or ideal. Additionally, these application dates do not require farmers to assess their unique field conditions and practices prior to application; prevents application at times when it may be more favorable; do not promote planning of dry season manrue applications; and do not prevent farmers from applying during unfavorable conditions, contributing to both possible surface and groundwater pollution. Instead, set dates encourage application in the fall when uptake is diminishing and rainfall and leaching potential is high (Paul and Zebarth, 1997; Beckwith et al., 1998; Almasri and Kaluarachchi, 2004; Hepperly et la., 2009), and allows spring application on a date that may encourage application during high precipitation events and/or when soil moisture is high, which can contribute to runoff (King and Tobert, 2007).

A system that uses a real-time, field-scale, and iterative methods to manure application would supplant the current rigid application dates listed above and instate a more fine-tuned approach to manure application timing. This system would assess the risk of manure application to surface and ground water using current field conditions (observed) and meteorological parameters (observed and forecast), as well as current conservation practices in place (i.e., setbacks, buffers, precision nutrient management). Along with a detailed field risk analysis and informational tools, the removal of rigid dates (Whatcom County Manure Ordinance 98-074, Chapter 16.28 rules and guidelines will still apply) inserts a level of flexibility that allows manure application to be done in a *more* responsible manner, while also allowing adjustment for the unpredictability of seasonal weather conditions and a changing climate. This will help prevent application during risky times and support application at times when it is appropriate and poses the least threat to resources.

The objective of this project was to develop a comprehensive manure Application Risk Management (ARM) system to help farmers reduce their risk of manure induced pollution through real-time, science based decision making tools to assist farmers in choosing the proper timing and location of manure application. This included a real-time Manure Spreading Advisory, Application Risk Management Worksheet, and seasonal manure application setback distances, all backed by field scale data collection and demonstration.

Because Whatcom County shares similar soil types, weather profiles, and farming practices, the data collected by this project was used to create tools that will cover the entire Puget Sound region.

8.1. Project Deliverables/Objectives

- Field-level risk assessment mapping process that identifies protection areas and gives individual risk ratings for runoff and leaching potential based on 15 aspects of soil properties and field characteristics. The risk assessment map shows runoff and leaching risks on a seasonal and temporal level by individual farm field and County wide.
- Manure Spreading Advisory, based on 72-hour precipitation forecast, gives farmers a real-time idea of current runoff risk via a color-coded, interactive, web-based map.

- Application Risk Management (ARM) Worksheet which provides an overall risk rating for a specific field based on forecast, soil characteristics, application technology, current field conditions, and protective measures. This Worksheet can be used as both an assessment tool and recordkeeping technique.
- Dynamic seasonal Manure Application Setback Distance guidance which provides additional protection and optimal field use throughout the year.
- Website (www.wadairyplan.org) that provides access to all tools mentioned above as well as educational information on manure risk management.
- Outreach and education opportunities on proper manure management for producers, partners, and colleagues through meetings, presentations, publications, and conferences.

The desired outcome of this project was the implementation of a more comprehensive and effective manure application management system that will reduce runoff and leaching events, decrease the fecal coliform and nutrient loading into the Nooksack and Strait of Georgia Watersheds, increase the vitality of freshwater fish and marine shellfish areas, increase surface and groundwater quality, and improve natural resources for the community. Additionally, by giving farmers a more active and responsible role in the management of their land, we hoped to reinvigorate the sense of environmental stewardship and reconnect farming to the community.

Three distinct areas of tool development were conducted in this project: 1) field level risk assessment mapping, 2) Manure Spreading Advisory (MSA), and 3) Application Risk Management (ARM) Worksheet. All three are individually presented herein.

9. FIELD LEVEL RISK ASSESSMENT MAPPING

Both a county wide and field level risk mapping exercise was conducted to determine the broad risk of runoff or leaching in Whatcom County, as well as at the field scale. The larger scale process was used to identify “hot spots” or areas of the County that were at a higher risk for either runoff or leaching potential and would benefit most from a targeted approach for risk management. This same process was also used on a micro scale with individual farms to assess the risk level associated with manure application to specific farm fields at different times of the year.

9.1. Countywide Assessment

A countywide assessment was conducted by creating GIS (ESRI, ArcMap) map layers based on soil types to characterize the runoff or leaching risk for Whatcom County. First, all of the available NRCS soil type characteristic and property data was downloaded from the Web Soil Survey (http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm) for Whatcom County. Next, the data for runoff and leaching was identified in the data set and each soil type was characterized into High (red), Medium-High (orange), Medium (yellow), Medium-Low (green), and Low (blue) risk separately for runoff and leaching. The color was overlaid into the existing soils GIS layer to make a new Risk Rating GIS layer (Figure 9.1).

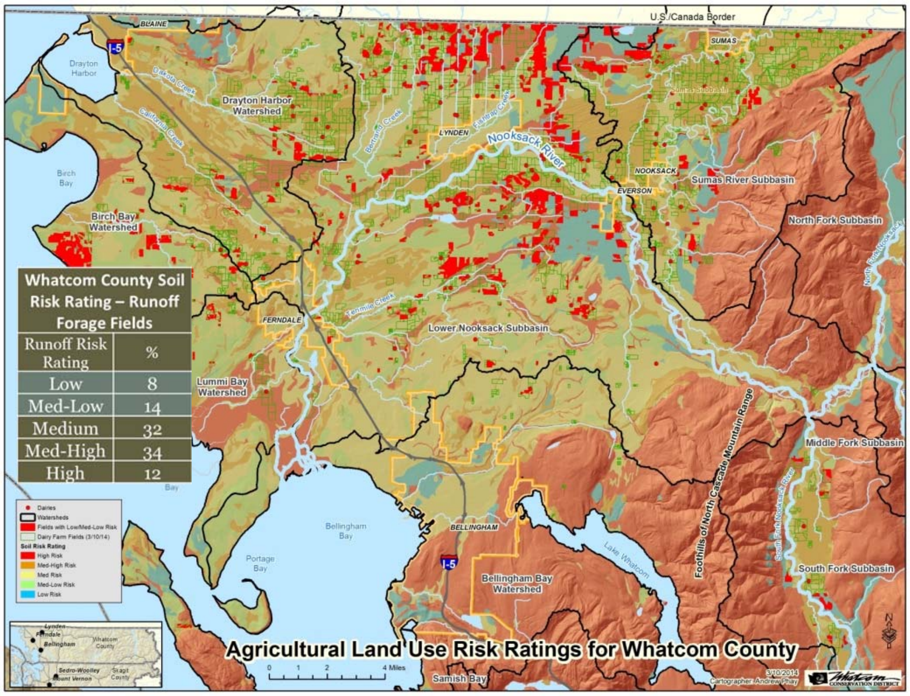


Figure 9.1. Runoff risk assessment for Whatcom County soils. This is a macro-scale assessment of runoff risk. For each map, red = high, orange = medium-high, yellow = medium, green = medium-low, blue = low risk. Green polygons represent farm field s attached to dairy operations. Red polygons show low risk fields associated with dairy fields.

Because of the broad assumption of a direct connection between soil type and runoff or leaching potential, the layer is not always accurate. Therefore a field level analysis needed to be conducted to take into account the field scale variables in not only soil type, but field characteristics such as topography, crop type, or slope.

9.2. Field Level Assessment

A more precise field scale runoff and leaching risk rating process was developed to create site specific field maps for farms. Again we used the available soil type information from NRCS soil survey and built it into an Access Database (Microsoft, 2010) that auto loaded the data based on a dropdown menu of soil types. The soil type data included soil type, average slope, seasonal high watertable depth, months of high water table, hydrologic group, available water holding capacity, permeability rate, drainage rate, flooding potential, ponding potential, compaction potential, and runoff rate. Additional data entered by observation or other mapping layers included aquifer recharge rate (data accessed from local CAO), potential runoff to surface water, wetlands present/possible, tiles present, crop type, acres, and any special consideration areas. Using the available data, along with a visual site assessment of each field do verify mapping information, a runoff and leaching risk rating were determined. The database then produced color coded tables showing all entered soil and field characteristic information as well as risk ratings assigned to each soil type (Figure 9.2).

Application Risk Management Index
Field Analysis
Wednesday, March 16, 2016

Risk Rating Guide		# Acres
1	High	67
2	Med-High	12
3	Medium	10
4	Med-Low	3
5	Low	46
	Total Acres:	138

Early Season Acres Available: 59

A - WCD

*The risk rating is for a grass/forage field. If in corn, special considerations apply which increases the risk level. See the DNMP for more information.

Field #	Primary Soil Type	Acres	Average Slope	Watertable Depth	Months of High Watertable	Hydrologic Group	AWHC	Permeability Rate	Drainage Rate	Drainage Rate (if tiles Present)	Ponding	Flooding	Compaction	Runoff	Runoff Potential to Waterway	Aquifer Recharge	Wetlands Present/ Possible	Special Consideration Areas Present	Tiles Present	Runoff Risk Rating	Leaching Risk Rating
			Soil Characteristics								Field Limitations					Resource Limitations					
1	BIRCHBAY SILT LOAM (13)	3	3-8	2.0-4.0	Dec-Apr	C	High	Moderate	Moderate Well		None	None	Severe	Moderate	☐	Moderate	☐		☐	Med-Low	Medium
1	LABOUNTY SILT LOAM, DRAINED (94)	10	0-2	1.0-3.0	Nov-May	D	High	Moderately Slow	Poor		None	None	Severe	Low	☑	Moderate	☑		☑	Medium	Medium
1	WHATCOM SILT LOAM (178)	12	0-3	1.5-3.0	Dec-Apr	C	High	Moderate	Moderate Well		None	None	Severe	Low	☑	Moderate	☑	Swale	☐	Med-High	Medium
2	HALE SILT LOAM (61)	52	0-2	0.5-2.0	Nov-Apr	D	Moderate	Moderate Rapid	Poor	Poor	Probable	None	Severe	Low	☑	Low	☑		☑	High	Low
3	KICKERVILLE SILT LOAM (79)	46	0-3	>6.0	n/a	B	High	Moderate Rapid	Well		None	None	Severe	Low	☐	High	☐		☐	Low	High
4	EDMONDS-WOODLYN LOAMS (45)	15	0-2	1.0-2.5	Nov-Apr	D	Low	Moderate Rapid	Poor		None	None	Severe	Low	☑	Low	☐	Ponded area drains	☐	High	Low
	Total Acres:	138																			

Figure 9.2. Copy of example ARM soils assessment form used for creating runoff and leaching risk assessment maps.

The table was used to create farm specific field maps for runoff or leaching risk potential using GIS (ESRI, ArcMap). The maps were color coded with High (red), Medium-High (orange), Medium (yellow), Medium-Low (green), and Low (blue) risk (Figure 9.3). The runoff risk maps were suggested for use between October-May, and leaching maps from June-September. The objective of the maps is to assist the land owner in selecting the appropriate field for manure application at any time of the year.

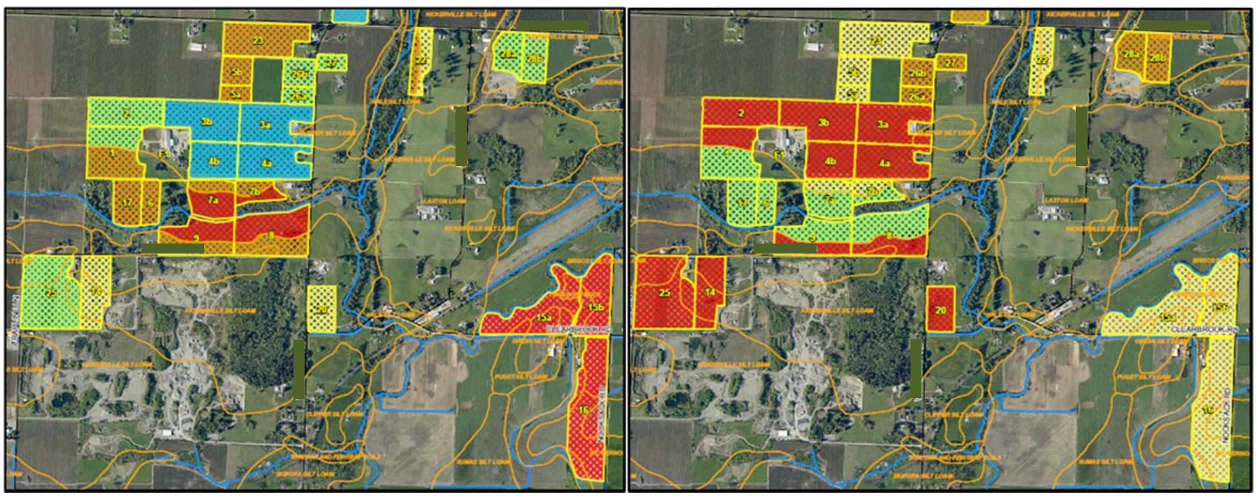


Figure 9.3. Runoff (left) and leaching (right) risk assessment maps for a specific farm. This is a micro-scale assessment of field risk. For each map, red = high, orange = medium-high, yellow = medium, green = medium-low, blue = low risk.

10. MANURE SPREADING ADVISORY

10.1. MSA Overview

A real-time Manure Spreading Advisory (MSA) was designed for the entire Western Washington region that gives a three day runoff risk rating along with 24-hour and 72-hour precipitation forecasts (Figure 10.1). Additional information accessed on the MSA includes the current Manure Application Setback Distance, link to the NOAA forecast for that point, and link to the ARM Worksheet. The MSA is presented in a real-time color-coded map that is updated each day at 0600 hours.

10.2. MSA Materials and Methods

The MSA map polygons, or precipitation groups, were created using the USDA average annual precipitation map 1971-2000 (USDA-NRCS Washington Average Annual Precipitation) which provides annual average precipitation in two-inch isopleths across Whatcom County. Local topography was also taken into consideration in differentiating polygons. Once a polygon was created, a forecast location was selected within the polygon that was representative of the entire area. The precipitation forecast location and data was taken from the NOAA National Weather Service website Forecast Weather Table Interface. Data was automatically downloaded daily in XML format for each of the 104 precipitation groups created and presented on the MSA map, plus seven validation locations.

NOAA provides precipitation forecast information in six hour blocks for up to six days. We choose to present the 24-hour forecast for five days and 72-hour forecast for three days, but only use 72 hours (three days) as the maximum for risk ratings, as accuracy of the prediction tends to decrease significantly after that (see Section 10.3 for more detail). Additionally, the 72 hours after manure application tends to be the most critical in terms of runoff probability. The 24 hour and 72 hour precipitation accumulation was calculated and automatically recorded and stored into a database along with the corresponding risk rating. The calculated data from NOAA was then linked together with the associated polygon for that station and displayed on a map. The polygons were colored differently depending on the precipitation accumulated totals and assigned risk rating for the 72-hour cumulative risk rating calculated on that day; red = High, orange = Med-high, yellow = Medium, green = Low (Table 10.1). Each of the polygons are clickable and show the calculated data in a easy to read table in a popup (Figure 10.1).

Table 10.1. Manure Spreading Advisory (MSA) risk rating and corresponding precipitation threshold

Risk Rating	Corresponding Risk Rating Color	72-hr Precipitation Threshold (in)
High	Red	>0.50
Medium-High	Orange	0.25-0.49
Medium	Yellow	0.10-0.24
Low	Green	<0.10

The MSA is hosted on the Whatcom CD website (www.whatcomcd.org/MSA) as well as a new website that was created through this project: www.wadairyplan.org/MSA (Figure 10.1). In both cases, the MSA map was embedded into the webpage using iMaps. A link to a larger map was included, along with a link to a mobile optimized map that could be used with a smart phone or touch tablet. The user is instructed to zoom into their field area and then click the map to access the pop up window with risk information. Information presented in the window includes the current manure application setback distance, precipitation ground ID, current runoff risk, advisory date, link to the NOAA weather forecast table for that polygon, and a table that presents five days of information including the date, 24-hour precipitation, 72-hour precipitation, risk rating, and link to the ARM worksheet which autofills the precipitation information when accessed from the MSA.

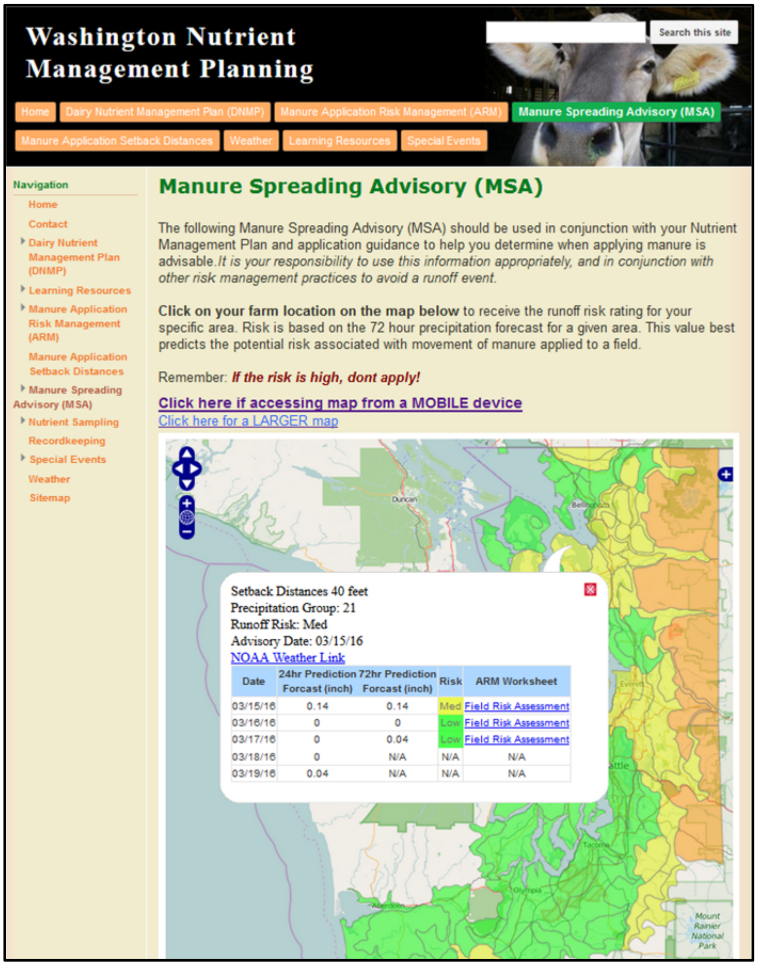


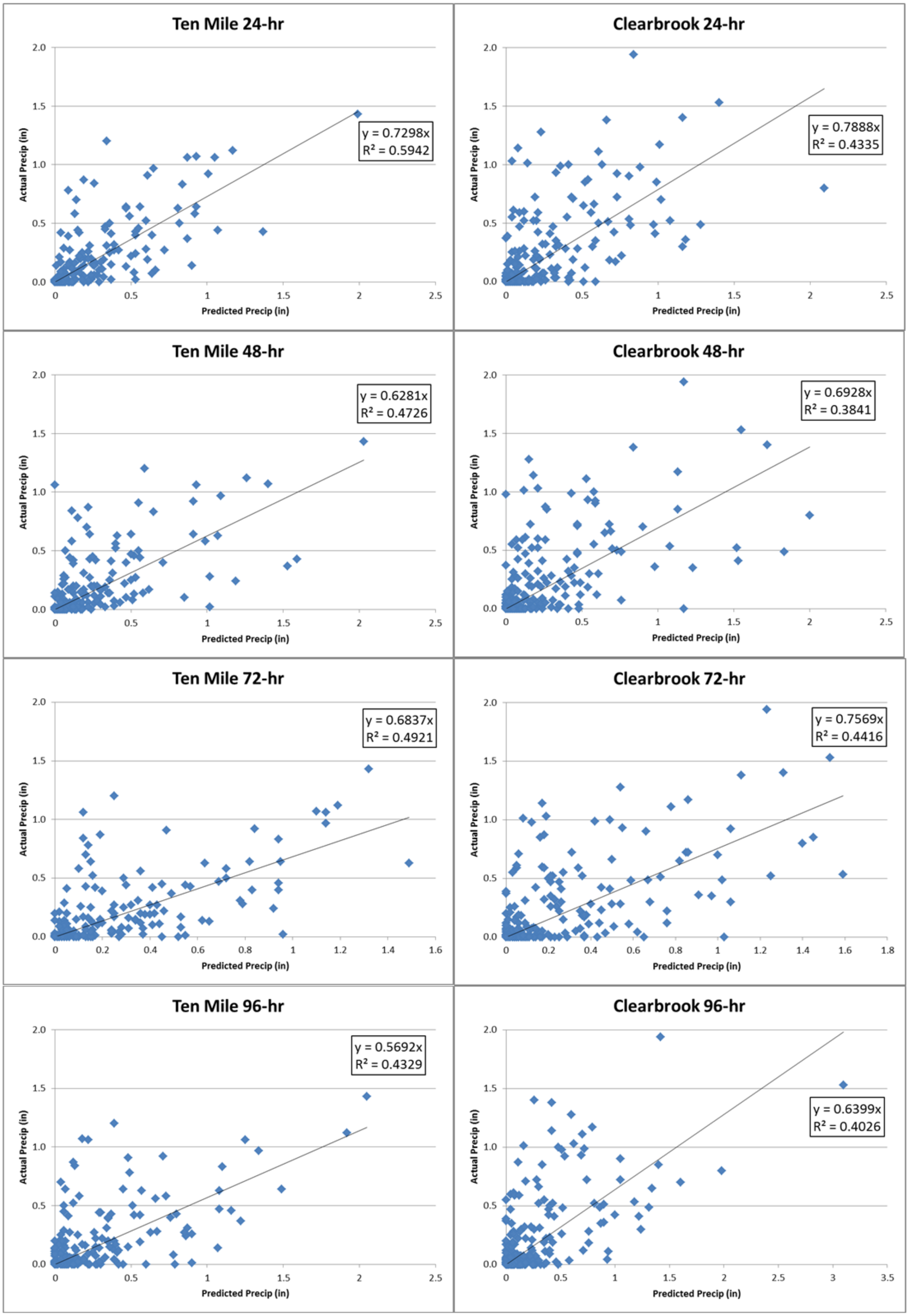
Figure 10.1. Screen shot of the Manure Spreading Advisory (MSA) accessed at www.wadairyplan.org/MSA on March 15, 2016. The MSA shoes the 24-hour and 72-hour precipitation forecast, current application risk rating, current manure application setback distance, link to ARM worksheet, and link to current NOAA forecast for the point accessed.

10.3. MSA Results and Discussion

10.3.1. MSA Output Validation

The MSA is only a useful tool if it provides fair, accurate, and effective outputs and guidance. We assessed the NOAA precipitation forecast verses actual precipitation for seven locations that had reliable precipitation recording from 2012-2015. We present the results from two stations, Ten Mile (WSU AgWeatherNet) and Clearbrook (NOAA), that were located near the sample sites.

In order to validate the accuracy of the MSA output, we looked at the regression and coefficient of determination (R^2) for the predicted verses actual precipitation for two sites, Ten Mile and Clearbrook. We found that the two values were more closely related on the day, or 24 hours, of the forecast (R2 = 0.43 and 0.59, Clearbrook and Ten Mile, respectively), and tended to decrease over the five days of forecast data available (Figure 10.2).


Ten Mile 24-hr
y = 0.7298x
R² = 0.5942
Actual Precip (in)
Predicted Precip (in)
Clearbrook 24-hr
y = 0.7888x
R² = 0.4335
Actual Precip (in)
Predicted Precip (in)
Ten Mile 48-hr
y = 0.6281x
R² = 0.4726
Actual Precip (in)
Predicted Precip (in)
Clearbrook 48-hr
y = 0.6928x
R² = 0.3841
Actual Precip (in)
Predicted Precip (in)
Ten Mile 72-hr
y = 0.6837x
R² = 0.4921
Actual Precip (in)
Predicted Precip (in)
Clearbrook 72-hr
y = 0.7569x
R² = 0.4416
Actual Precip (in)
Predicted Precip (in)
Ten Mile 96-hr
y = 0.5692x
R² = 0.4329
Actual Precip (in)
Predicted Precip (in)
Clearbrook 96-hr
y = 0.6399x
R² = 0.4026
Actual Precip (in)
Predicted Precip (in)

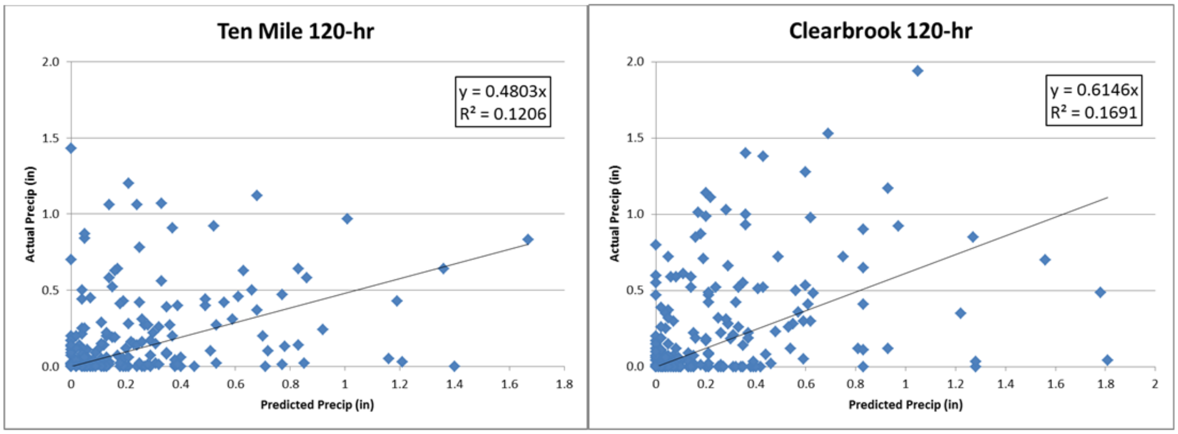


Figure 10.2. Regression graph and coefficient of determination (R^2) for the predicted verses actual precipitation amounts for the Ten Mile and Clearbrook stations for five days of forecasting from NOAA.

In general, the forecast tended to over predict the precipitation amount, particularly during the spring months (March-May). However, regression looks at the exact value of predicted verses actual precipitation and the MSA produces risk ratings in ranges. It is fair to give a 10-20% margin on each end of the forecast, meaning that the correlation would significantly improve. When values are put in ranges to produce the three day cumulative runoff risk rating, the confidence is much better (R^2 = 0.69 Clearbrook, R^2 = 0.65 Ten Mile) (Figure 10.3). Meaning that the risk rating presented in the MSA the day of application consideration was representative of the actual conditions seen for the sites reviewed. If changes in the risk rating ranges were made, this analysis would need to be conducted anew.

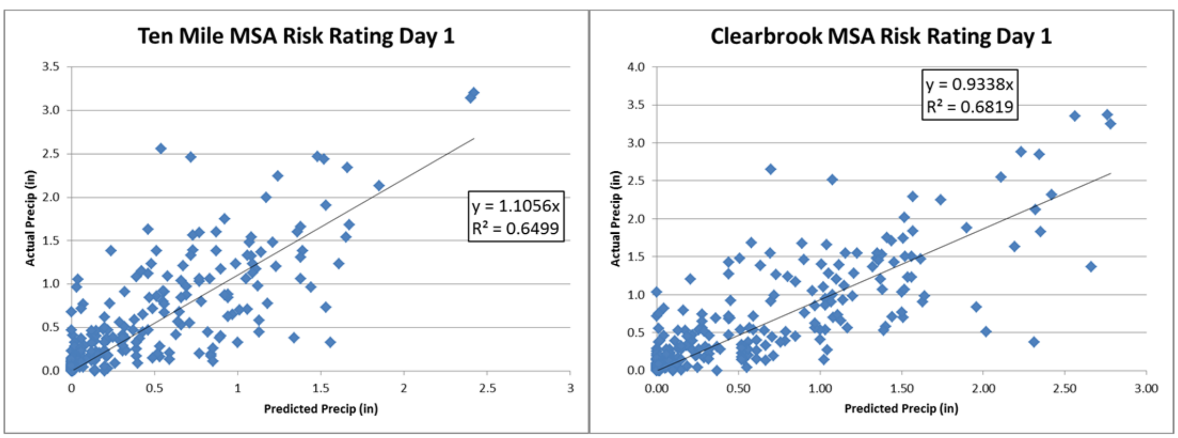


Figure 10.3. Regression graph and coefficient of determination (R^2) for the predicted verses actual precipitation amounts for the Ten Mile and Clearbrook stations for three day runoff risk rating presented on the day of application.

Based on our analysis, we concluded that the risk rating presented in the MSA was accurate enough and representative of actual conditions to act as a general predictor of runoff based on the criteria set forth.

10.3.2. MSA Use Rate

We used Google Analytics to track the use rate of the MSA from its inception in February 2014 to current March 2016. We were able to see how many users accessed the MSA webpage and when (Figure 10.4). The annual average use increased 6% from 2014-2015, and 87% from 2015-

2016 due to outreach efforts and exposure of the tool. Additionally, we can see that users accessed the page primarily in the spring and fall seasons when runoff risk is higher due to precipitation events, indicating that he tool is being used when intended.

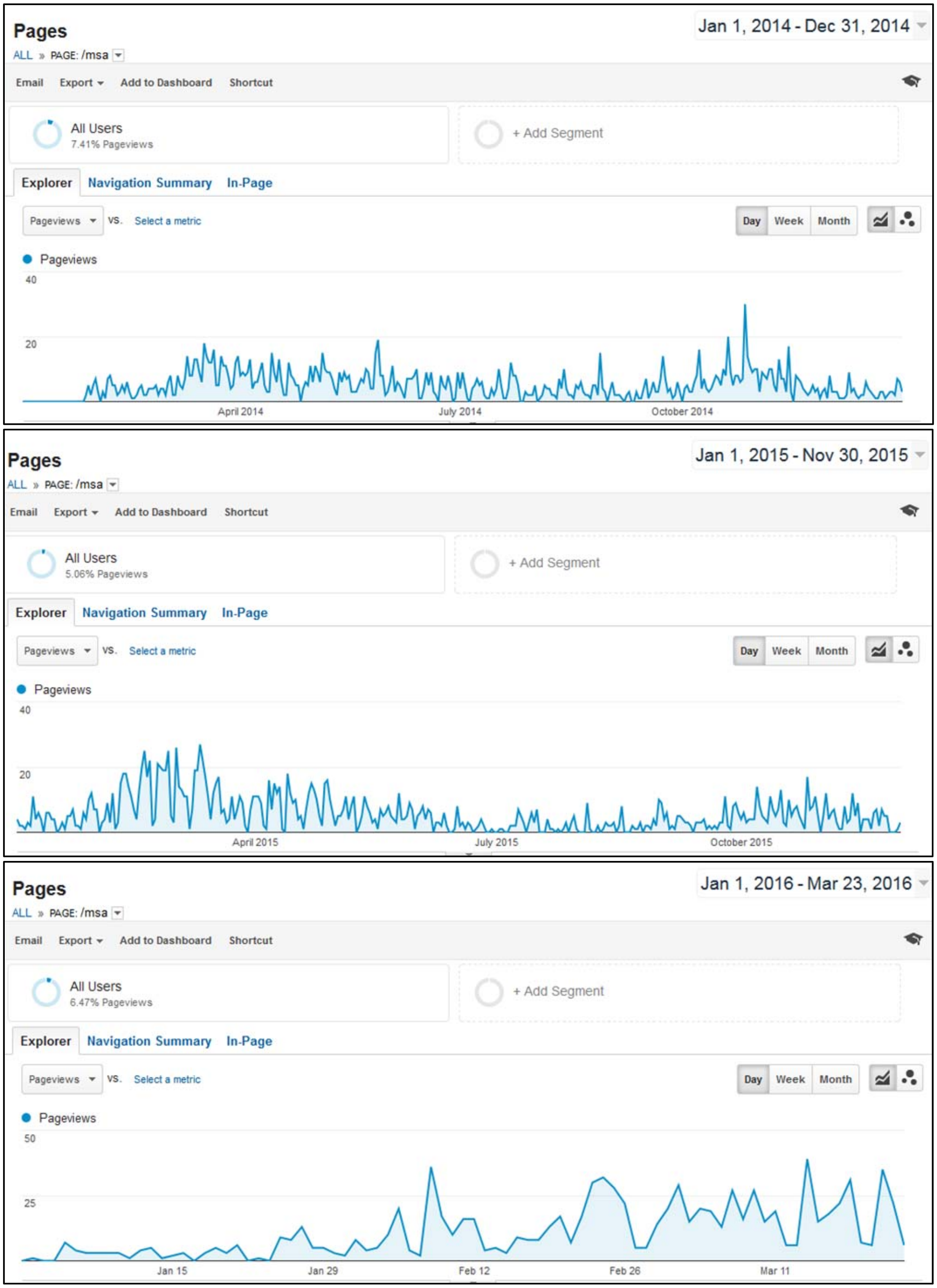


Figure 10.4. Manure Spreading Advisory (MSA) use statistics as presented in Google Analytics for 2014, 2015, and 2016. This data was accessed for the Whatcom CD MSA webpage on March 23, 2016.

11. APPLICATION RISK MANAGEMENT (ARM) WORKSHEET

11.1. ARM Worksheet Overview

The heart of the project was the development and testing of an Application Risk Management (ARM) Worksheet that assists a land owner in conducting a field-level manure application risk assessment in real-time. The parameters chosen were based on best available science, practical considerations, and field testing.

11.2. ARM Worksheet Materials and Methods

Prior to application of manure to any field, any time of the year, a producer completes the ARM worksheet which evaluates runoff potential and provides feedback for proper application techniques. The Application Risk Management (ARM) Worksheet is divided into different categories that we determined capture the most salient conditions that affect the level of risk associated with a runoff event from manure application (Figure 11.1):

- Farm Information
- Application Date
- Precipitation Forecast
- Soil Type
- Soil Moisture
- Water Table Depth
- Forage Density
- Forage Height
- Field Surface Conditions
- Manure Application Equipment
- Waterbody or Critical Area Present (Setbacks and Buffers)

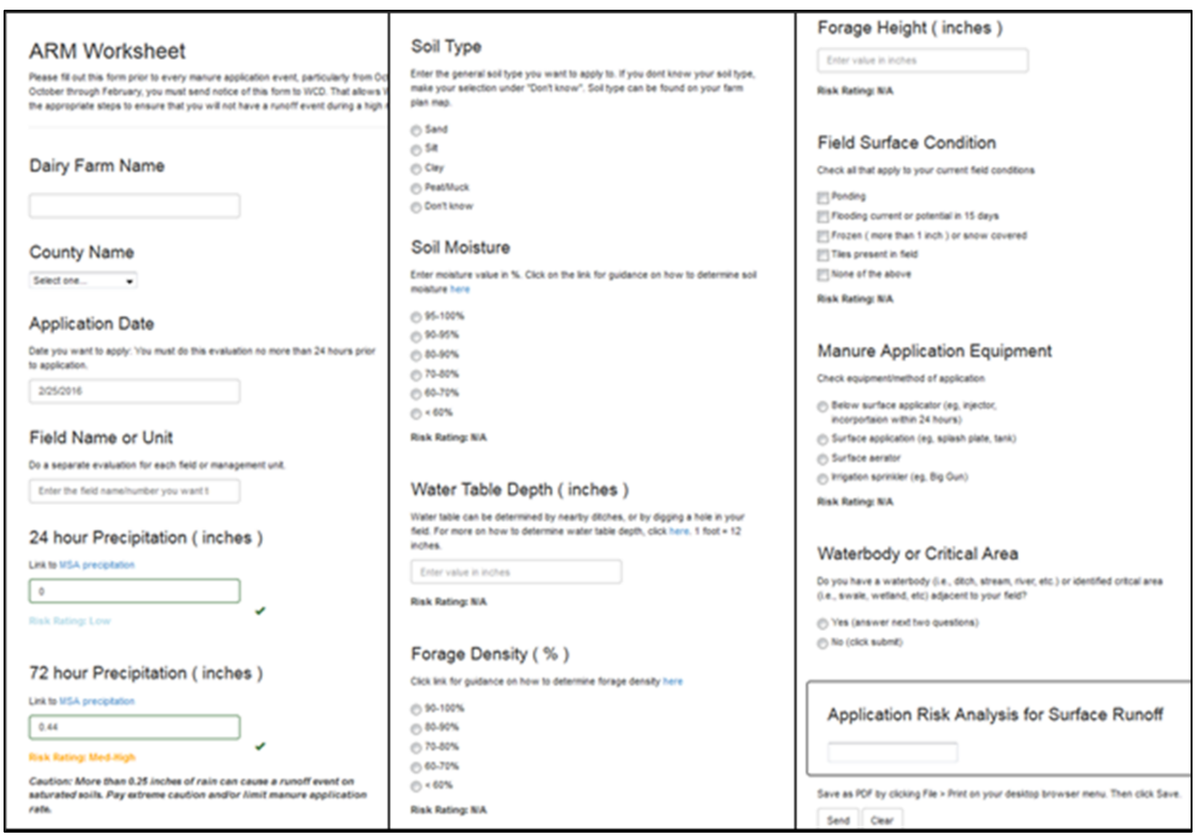


Figure 11.1. Example of the Application Risk Management (ARM) worksheet. A user fills in the data fields specific to their current field conditions no more than 24-hours prior to manure application.

A user accesses the ARM Worksheet via link or the Manure Spreading Advisory (MSA) (www.wadairyplan.org/MSA), which auto loads the 24-hour and 72-hour precipitation forecast information. They then fill out the required field information no more than 24 hour prior to application. This is because weather and field conditions can change significantly outside of that window and we wanted to ensure it remained valid. A new worksheet needs to be completed for each field, or group of same fields, each day. If an application event will take multiple days, the user is asked to fill out the worksheet for day one, then watch the MSA each day for changes in the forecast and act accordingly.

As the user enters information, the worksheet provides an individual risk rating and feedback information specific to each parameter entered. Each parameter is given a value between 1 and 10 (1=Low, 2=Low-med, 3=Low-Med, 4=Medium, 5=Medium, 6=Medium, 7=Med-High, 8=Med-High, 9=High, 10=High). All values are added at the end of the worksheet to provide an overall risk rating for application to that field on that day. The risk ratings for each entered parameter are based on threshold values that consider "optimal" conditions. These values were calculated based on best available science, scientific literature, and/or values measured through field evaluations in this study. If at any point a user enters in a value that is deemed "High" for any parameter, a message will be presented that no application is recommended and the worksheet will have an "Extreme" rating. The threshold values for each parameter, along with the reasoning for each parameter, are described herein.

11.2.1. Farm Information

The user is asked to enter in the Farm Name, County, Application Date, and Field Name. All of this information is collected for their identification and recordkeeping purposes.

"Dairy name" – This information is for identification of user and accountability.

"County Name" – Because the MSA is Puget Sound wide, this field identifies the county they are in so the worksheet can be routed to the correct Conservation District for review. Oregon also has an MSA that uses the same worksheet, so their counties were also included.

"Application Date" - The current date autofills into the worksheet and gives a reference of when the worksheet was filled out. This allows the checking of forecast predictions and a reference for criterion to be adjusted date (i.e., manure setbacks). It is recommended that the Worksheet assessment be done no more than 24 hours prior to application so that the forecast is current and accurate, and that field conditions have not changed significantly over a period of time. If more than 48 hours has passed between assessment and proposed application, the producer was contacted and asked to redo the Worksheet based on current values.

"Field number(s) of name(s)" – This is to identify which fields are being applied to. When compared to the individual field risk analysis, this criterion should match with the recommended fields for that specific time of year or conditions. Every farm that participates in the ARM guidance is required to have a field risk mapping analysis conducted for each individual field. This guidance shows the runoff risk level for each field during the high risk seasons.

11.2.2. Precipitation Forecast

The 24-hour and 72-hour precipitation auto loads into the worksheet when a user accesses the worksheet from the MSA. This was set-up to ensure that all users access the same, proven, precipitation forecast information from NOAA.

“24 hour Precipitation” - This is one of the most important parameters effecting runoff potential. A small amount of rain (<0.10 inches) following application has been shown to help incorporate manure into the non-saturated soil profile, but a significant amount of rain (>0.50 inch) can induce a runoff event or cause rapid infiltration and leaching of soil nutrients below the vadose zone and into the groundwater.

“72 hour Precipitation” – This is the total cumulative amount of rain predicted in the 72 hours following manure application and is a measure of the potential for a runoff event. The reason a longer period is not used, is that the forecast accuracy decreases significantly after three or four days.

Table 11.1 Precipitation Forecast risk thresholds for ARM Worksheet

Risk Rating	Precip Forecast	
1=Low, 10=High	24-hr Forecast (in)	72-hr Forecast (in)
1	0	0
2	0.01	0.05
3	0.05	0.1
4	0.08	0.2
5	0.1	0.25
6	0.15	0.3
7	0.2	0.35
8	0.25	0.4
9	0.35	0.45
10	0.5	0.75

11.2.3. Soil Characteristics

“Soil Type” – The user enters in the predominate soil type (sand, silt, clay, peat/muck, or “don’t know”) for their field, which is found on their risk maps. Soil type characteristics, such as infiltration rate, percolation, and flow velocity dictate the potential for runoff and leaching from an individual field. For example, if the soil has a high percentage of smaller silt and clay like particles, as opposed to sand and loam soil types, runoff potential will be greater. This is because the settling and infiltration rate for clay verses sandy soils is less, which tends to disfavor fecal coliform and nutrient absorption into soils (Roodsari et al., 2005). The soil type criterion entered here is used to adjust the threshold criteria used in the Worksheet for soil moisture.

“Soil Moisture” – Soil moisture is an important measure of the ability of the soil to hold water rather than let it remain on the surface and be subject to movement. This value is strongly linked to soil type, and therefore, the risk rating for soil moisture was adjusted based on the soil type entered in the worksheet. The soil moisture selections in the worksheet were provided in ranges.

“Water Table Depth” – Water table depth can be determined by visual appraisal of nearby ditches or tiles, or by digging a temporary hole down to at least two feet. The closer the water table is to the surface, the more likely the transfer potential of nutrients to surface and groundwater. Application on a field with a seasonal high water table level within 12 inches of the field surface is not recommended. A medium to high level of risk is associated with application to a field with a water table within 24 inches of the surface. Below 24 inches, the route of transference for recently applied manure should be lower when accompanied by agronomic application practices.

Table 11.2 Soil Characteristic thresholds for ARM Worksheet

Risk Rating	Soil Moisture				Water Table
1=Low 10=High	General - Soil Moisture (%)	Sand - Soil Moisture (%)	Silt - Soil Moisture (%)	Clay/Peat/Muck Soil Moisture (%)	Water Table Depth (in)
1	60	60	60	60	48
2	70	70			40
3			70		36
4		80		70	30
5	80		80		28
6				80	24
7	90	90			20
8			90		18
9				90	16
10	95	95	95	95	12

11.2.4. Field Vegetation Cover

The Field Vegetation Cover category is an indicator of the surface protection offered by the density and height of the crop. The density and height of the vegetation cover are related to surface movement, nutrient uptake, and sediment capture. A bare field has no ability to limit movement and should not be applied to at high risk times of the year (October-April). Likewise, a grass or forage field will sparse stem density or very short vegetation cannot adequately protect critical areas from surface movement or sediment or nutrients and should not be applied to without proper protection (i.e., setbacks, vegetative buffers, reseeding).

“Forage Density” – The density of cover relates to the stem density of vegetation, or cover within a square grid of land. Vegetation cover affects the surface water flow, sediment deposition, and uptake of nutrients applied to a field. An increase in the density of vegetation cover has been shown to increase the settling and filtration capacity for sediment (Abu-Zreig et al., 2003) and fecal coliform (Roodsari et al., 2005) by slowing down the flow and increasing the infiltration capacity of the soil. Additionally, a denser stand of vegetation will filter out more particles due to sediment trapping and nutrient uptake potential. The density will also dictate the pattern of flow (i.e., sheet or concentrated) through the field; the greater the density of the vegetation, the more likely the flow will be the preferred sheet flow.

“Forage Height” – If the height of the vegetation is less than that of the runoff, the potential for runoff will be increased. It is recommended that vegetation be at least 3 inches to properly reduce runoff velocity. Conversely, if forage vegetation gets too tall, nutrient uptake will decrease and be more available for transport; therefore, vegetation should be maintained/ harvested if over 8 inches in height.

Table 11.3 Field Vegetation Cover thresholds for ARM Worksheet

Risk Rating	Field Vegetation Cover

1=Low 10=High	Forage Density (%)	Forage Height (in)
1	90	5
2	85	4
3	80	3
4	75	
5		
6	70	2
7		
8	60	
9	55	
10	50	1

11.2.5. Field Surface Condition

Certain field conditions including ponding, flooding, frozen ground, and tile discharge are all important factors related to manure application risk. Some of these factors will override manure application and produce a "No Application" recommendation such as flooding and frozen ground. These parameters were selected because they are listed in the NRCS Nutrient Management (590) Practice Standard (WA, 2014), and required to be assessed in recordkeeping.

"Ponding" – Manure application is permitted with great caution on fields with ponded areas. If the ponded area is contained and has no exit point to a waterbody, it is recommended that manure application stay at least 10 feet away from the area to reduce compaction and standing manure. If the ponded area has an exit point to a waterbody via surface or tile drainage, the appropriate manure setback for that specific time of year must be observed from the parameter of the ponded area.

"Flooding current or potential in 15 d" – Due to the extremely high risk of manure transport to waterways, no application is permitted on flooded or potentially flooded fields.

"Frozen or snow covered fields" – Due to the extremely high risk of runoff, no application is permitted on fields frozen more than 1 inch down or covered with more than 1 inch of snow.

"Tiles present" – Tiles have the potential to channel and discharge manure when coupled with high application rates, permeable soil types, saturated soils, or high water tables. For this reason, the presence of tiles in a field is a Medium risk and comes with a warning to observe tiles after application and immediately cap if any discolored liquid indicating manure transport is observed. Under ideal conditions, tiles are not a problem to apply over. However, with high water table, large soil pores due to animal or other activity, or saturated soils, tiles can be a direct conduit from the surface to tile discharge points.

Table 11.4 Field Surface Condition thresholds for ARM Worksheet

Risk Rating	Field Surface Condition			
1=Low 10=High	Ponding	Flooding	Frozen Ground	Tile Discharge
1	No	No	No	No
2				

3				
4	Yes			
5				
6				Yes
7				
8				
9				
10		Yes	Yes	

11.2.6. Manure Application Equipment

The type of equipment used to apply manure has an effect on the potential for runoff losses. In general, equipment that delivers manure below the field surface will have a lower risk for losses than an application method that delivers manure to the field surface. Likewise, equipment that gets manure below the leaf canopy is also more successful in reducing loses. We added the four most common methods of manure application equipment to our list including below surface or injection, surface, surface aerator, and irrigation sprinkler.

"Below surface application" – Equipment the delivers manure below the surface, such as injectors, and incorporation within 24 hours, is considered low risk for losses.

"Surface application" – Equipment that applies manure to the field surface, such as splash plate or tanker wagon, have a medium risk of losses in the wet season only because it delivers manure to the surface rather than subsurface.

"Surface aerator" – A surface aerator is a splash plate style applicator with an added drum that creates 4-6 inch plugs in the soil. This method is preferred in the wet months as It encourages some immediate manure infiltration into the soil, and also provides a soil aeration amendment.

"Irrigation sprinkler (Big Gun)" – Irrigation or Big Gun sprinklers are commonly used to apply manure because they can be pulled on wetter soils, apply a smaller volume of manure than other methods, and are relatively inexpensive. However, sprinkler application has the highest risk of volatilization, runoff, and drift losses. Sprinkler application must be managed with a higher level of oversight and thus carries a higher level of risk with use.

Table 11.5 Field Surface Condition thresholds for ARM Worksheet

Risk Rating	**Manure Application Equipment**		
1=Low 10=High	**Below Surface**	**Surface Application/Aerator**	**Irrigation**
1	No	No	No
2	Yes		
3			
4		Yes	
5			Yes
6			
7			
8			
9			
10			

11.2.7. Buffers and Setbacks

If a landowner has a waterway (i.e., ditch, stream, swale, wetland, etc.) adjacent to their field, they are asked two additional questions: what is their manure applications setback distance and do they have a vegetative buffer adjacent to the water body. Both of these questions are checks to ensure that proper practices are in palace.

"Manure Setback Distance" – A manure setback is the distance between the edge of manure application and a waterbody. Per Chapter 16.16 WCC of the Critical Areas Ordinance (CAO), and 16.28 WCC of the Manure and Agricultural Nutrient Management: "Unless it is pursuant to a management plan [DNMP] approved by the Whatcom conservation district, the spreading of manure within 50 feet of drainage ditches leading to rivers and streams is prohibited for buffer requirements on streams, rivers, and other bodies of water, see Chapter 16.16 WCC (Ord. 98-074; Ord. 98-056)." In some cases this distance is 100 feet without a DNMP per the CAO. NRCS recommendation or vegetative areas vary based on local and practice considerations (USDA, 2008). Therefore, all dairy fields are subject to manure setback distance guidelines as a means of limiting the potential for a runoff event. Setback guidelines developed concurrently with this project are based on both scientific evaluation as well as applied considerations (Embertson et al., 2012). The recommended minimum manure application setback distance is 80 feet October 1 through February 28, 40 feet March 1 through May 15 and September, and 10 feet May 15 through August 31. If using a sprinkler-type irrigation method such as a big-gun, the minimum setback is 40 feet March through September and 80 feet the rest of the year to accommodate drift.

"Vegetative Buffer" – A vegetative buffer is any area of vegetation between a field and waterbody. The type and width of a vegetative buffer will vary based on the individual site/field characteristics, but the vegetation should be maintained and vigorous. Per historical context, a buffer width of 35 feet is listed in the worksheet. A vegetative buffer can be the edge of a grass field, or a permanently planted grass area around a row crop field.

Table 11.6 Vegetative Buffer and Setback thresholds for ARM Worksheet

Risk Rating	Vegetative Buffers and Setbacks			
1=Low 10=High	Waterbody Adjacent	Veg Buffer in Place	Veg Buffer <35 feet	Veg Buffer >35 feet
1	No	Yes		
2				
3				
4	Yes			Yes
5				
6				
7		No	Yes	
8				
9				
10				

11.2.8. Risk Rating

At the end of the worksheet, an overall risk value is calculated and presented based on the risk rating of each parameter entered in the Worksheet. The overall risk rating is either: Low, Low-Medium, Medium, Medium-High, or High. At this time, the Worksheet only produces a risk rating for runoff risk. It is up to the user to take appropriate action based on the output of the worksheet.

Table 11.7 Overall risk rating cumulative values for ARM Worksheet

Risk Rating	Risk Category Range
High	>50
Medium-High	40-50
Medium	31-40
Low-Medium	25-30
Low	<25

The user is recommended to print the worksheet for their records. At this time, they also have the option of sending it their planner for review. This ensures that they did the assessment correctly and can receive feedback. Additional improvements and adjustments to the print and send capabilities of the sheet are on-going.

11.3. Use of the ARM Worksheet

The ARM Worksheet was developed with the intention of identifying times and conditions where manure application was and was not appropriate. By going through a process of analysis and review, producers should be able to identify those criteria that either prohibit application or deem it acceptable, and develop a sense of adaptive management. In that way, the ARM Worksheet is a decision aid tool. Once a user receives the risk rating, they use it as a guide in deciding how to move forward with manure application. If the risk is high, the recommendation is to not apply as the risk of having a runoff event is great. Additionally, the worksheet output needs to be used in conjunction with good manure application practices. Just because the risk is low does not mean that poor manure practices won't cause a runoff event. Any error in judgment by the producer that creates a discharge event is subject to penalty by the appropriate regulatory agency.

The parameters and thresholds in the ARM Worksheet were based on best available science and results from the ARM field study. They will continue to be improved as new information becomes available.

11.4. ARM Worksheet Results and Discussion

All producers enrolled in the field trials, as well as tool review, provided ongoing feedback on the functionality and accuracy of the ARM tools (i.e., MSA, ARM worksheet, setbacks). In order to remain in the ARM program, producers had to follow all guidelines and recommendations set forth, and provide constructive feedback.

During the project period, to ensure producers accurately filled out and understood the ARM Worksheet, an accountability system was implemented where all worksheets were submitted to WCD prior to application for approval before manure was applied. This allowed the project to review areas where users had challenges with the worksheet and correct them. At the beginning of the project, the worksheet was created and used in Excel (Microsoft, 2010). It was discovered that this was not only limiting, but that some users did not have access to Excel. Additionally, some users wanted the sheet accessible on their smart phones in the field. To accommodate these needs, the worksheet was finalized in a web accessible format that allowed all users to access it from multiple electronic devises. It also allowed all tools to be integrated for efficiency and auto-loading of information.

We discovered in working with producers and reviewing worksheets, that the hardest criteria to fill out were the precipitation forecast and soil moisture. The precipitation forecast varied greatly by user depending on where they accessed the information. We solved this by making the 24-hour and 72-hour precipitation forecast auto load into the MSA when we went to a web format. This gives us a greater confidence in the data. The soil moisture was also difficult for users to determine. We went to greater ranges in the worksheet (15-25% verses 5-10%), acknowledging that a small rage was more difficult to determine and did not actually improve the validity of the worksheet. There is not an easy, accessible method to determine soil moisture such as a thermometer-type probe, and the recommended method is via a hand test which takes time and experience. We posted soil moisture determination how-to guidance (USDA, 1998) on the webpage and are conducting educational soil field days in 2016 to help farmers determine soil moisture.

Currently, the regulatory agency enforcing on dairy operation activities is WSDA. The penalty details and enforcement capabilities on the ARM program were discussed. It was decided that at this time, the ARM system and tools would be a voluntary process to assist a landowner in making an informed decision about manure application. They are still under all regulatory requirements and penalties associated with discharge events.

12. MANURE APPLICATION SETBACK DISTANCES

12.1. Setback Overview

The manure application setback distance, which is independent of vegetative filter widths, varies with season, soil type characteristics, and/or vegetative state of a field. Manure setbacks can be used alone or in conjunction with any type of vegetative buffer practice. If used alone, it is recommended that the field be in perennial forage production or have a healthy stand of annual forage growing. For Whatcom County, the setback distance moves throughout the year based on general farming practices and historical precipitation times, and is the same for liquid or solid manure application.

Per Chapter 16.16 WCC of the Critical Areas Ordinance (CAO), and 16.28 WCC of the Manure and Agricultural Nutrient Management: “Unless it is pursuant to a management plan [DNMP] approved by the Whatcom conservation district, the spreading of manure within 50 feet of drainage ditches leading to rivers and streams is prohibited for buffer requirements on streams, rivers, and other bodies of water, see Chapter 16.16 WCC (Ord. 98-074; Ord. 98-056).” In some cases this distance is 100 feet without a DNMP per the CAO. NRCS recommendation or vegetative areas vary based on local and practice considerations (USDA, 2008). Therefore, all dairy fields are subject to manure setback distance guidelines as a means of limiting the potential for a runoff event.

12.2. Setback Determinations

A concurrent literature review and analysis was conducted to determine effective and practical manure application setback distances. This project did not have the opportunity to test the recommended setbacks during this project, but a future project is underway to test them against a control and alternative strategy to ensure they are protective of water quality under a variety of conditions. This information is presented here as an explanation of the setback distances listed throughout this project.

The manure application setback distances mentioned in this project are presented below (Table 12.1). They are still in testing. It should be noted that this is general information. Specific field and producer considerations are taken into account when designing their individual Dairy Nutrient Management Plan or Farm Plan that specifies their unique setback distances as appropriate. That means that larger setback distances may be recommended under certain circumstances where critical areas such as swales, wells, fence lines or protected waterways are present, or where there is a slope greater than 9%. This guidance is assessed on a field-by-field basis.

Table 12.1. Manure application setback distances recommended in conjunction with the ARM project

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
80[4]	**80[4]**	**40**	**40**	**40/10[1,2]**	**10[2]**	**10[2]**	**10[2]**	**40**	**80**	**80[3,4]**	**80[3,4]**

[1]This is a floating date and should be evaluated based on current weather and forecast information.
[2]A big gun applicator should NEVER be closer than 40 feet at any time of the year due to drift.
[3]Application during November and December is typically not necessary and must be shown to be agronomic before manure is applied.
[4]Any manure application made from November-February must have a winter spreading plan in place.
These guidelines apply equally to both liquid and solid manures

The recommended minimum manure application setback distance is 80 feet October 1 through February 28, 40 feet March 1 through May 15 and September, and 10 feet May 15 through August 31. If using a sprinkler-type irrigation method such as a big-gun, the minimum setback is 40 feet March through September and 80 feet the rest of the year to accommodate drift. The shift from 40 to 10 feet on May 15th is recommended as a floating date and may not always be appropriate. The 10 foot setback is allowed during the summer months when rain events are very infrequent and precipitation amounts typically low. This allows fertilization and maintenance of the entire field to promote vigor and forage quality. It is recommended that anyone applying manure check their local forecast before applying at all times of the year and make adjustment to the setback distance as appropriate.

13. MANURE APPLICATION GUIDANCE AND OUTREACH

13.1. Manure Guidance

Based on the information collected through this project, a five step manure application diagram was created along with reference to the corresponding tools created by this project (Figure 13.1). This five step diagram was used in educational materials and presentations to highlight the iterative process and tools for each step.

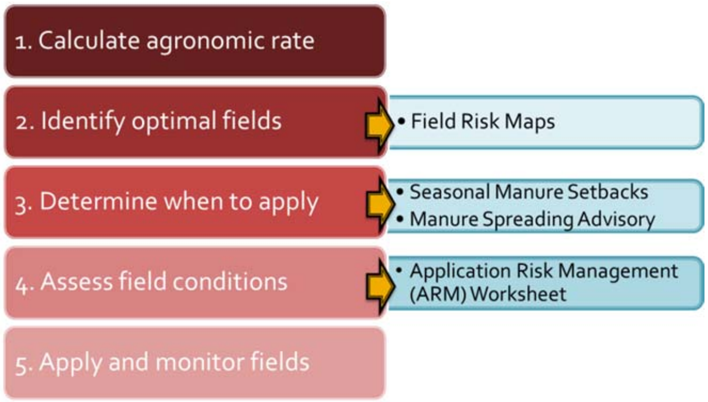


Figure 13.1. Schematic of manure application steps and corresponding tools created by this project.

13.2. Website: www.wadairyplan.org

In order to house the ARM project information and tools, a dedicated website was created, www.wadairyplan.org, and launched in 2014 (Figure 13.2). The website was created and beta tested with a few producers and users prior to launching to ensure it was easy to navigate and contained what was needed. The site was originally created for dairy producers, but has since be structured to appeal to all manure users to maximize viability and sue of the information and tools housed on the site. The website contains information on DNMP Information, Application Risk Management (ARM), Manure Spreading Advisory (MSA), Manure Setbacks, Weather, Nutrient Sampling, Recordkeeping, Learning Resources, and Special Events.

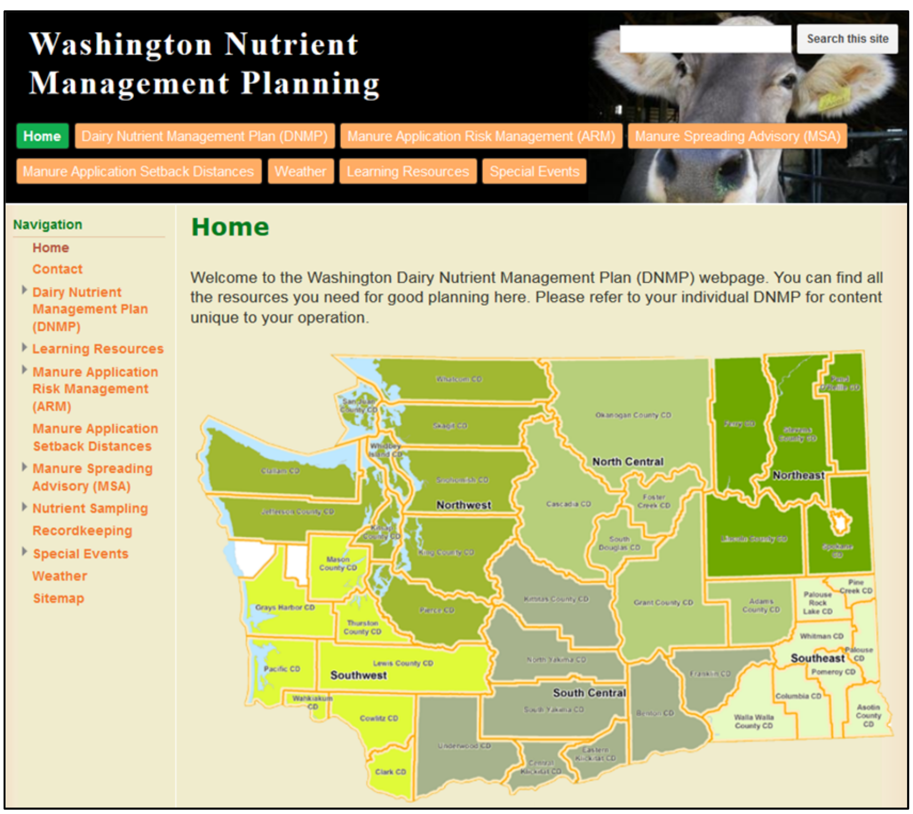


Figure 13.2. Screen shot from the WA Dairy Plan (www.wadairy plan.org) website of the home page. This website was created for this project to house the ARM system information and tools.

Using Google Analytics, user rate and activity of the website was assessed. While user rate volume changes throughout the year, the webpage currently receives approximately 110 users per month, primarily to the MSA page. From its launch in 2014, annual session use of the website has increased 159% from 2014-2015, and a further 253% from 2015-2016. The new verses returning user percentage has changed in favor of returning visitors (45% increase) indicating that users are assessing the site regularly. All of this information generally indicated that the webpage is increasing in use and that users are returning to the website, indicating that it is providing useful information.

13.3. Integration of ARM into Planning

Once the ARM system was evaluated and proofed scientifically, Dairy Nutrient Management Plans created or updated by WCD, and other participating CD's in Western WA, included the ARM system tools and manure use guidance. This was supported by WSDA, who manages the state Dairy Nutrient Management Program. The ARM system was also promoted in planning to other forms of agriculture that apply manure including berry and crop farmers, small farms, grazing operations, and other livestock (i.e., beef, horses).

Training events were conducted annually during the project period to inform and train planners how to use the ARM system planning tools and promote to their local producers. This ensured uniform, and proper knowledge, use and execution of the ARM system and tools.

13.4. Education and Outreach Efforts

The ARM system and its various components were shared in a variety of media throughout the project including: articles in Whatcom Dairyland News, Manure Matters, and Dairy Federation News; announcement and presentation at various stakeholder meetings including NRCS, WSDA, EPA, and DOE; creation and dissemination of handouts to producers; field tours for NRCS, EPA, WSDA, Waste to Worth Conference, and others; lectures at WWU and WSU; presentation at professional conferences including Waste to Worth 2013 and 2015, Soil and Water Conservation Society 2015, Salish Sea Conference 2012 and 2016, National Association of Conservation Districts Annual Meeting 2015, and BC Agriculture Air and Nutrient Workgroup 2010-2016. The ARM system was presented in detail directly to producers at the annual Manure Nutrient Management Training Events in Whatcom (2015, 2016), Snohomish (2016), and King (2016) counties. Additional presentations and feedback sessions with dairy producers were conducted at the Whatcom Dairy Speaker Series annually from 2011-2016. Lastly, annual EPA partner meetings were conducted annually to share data and receive feedback from advisory partners.

14. ARM FIELD MEASUREMENTS

The ARM tools presented were tested and validated in the field at actual dairy farms. A significant part of the project was implanting the ARM manure application system and testing it against conventional manure application practices. A large amount of field data was collected to assess the cycling of manure nutrients in the soil-water-plant cycle. The information presented in this section outlines and describes the field sampling portion of the project.

14.1. Project Location and Site Description

This project was conducted in western Whatcom County, WA in north Puget Sound (Figure 14.1). The grant targeted two adjacent watersheds in Whatcom County: the Nooksack and the Strait of Georgia. These two watersheds encompass 1,687 mi^2 bordered by the Cascade Mountain Range to the east, Canada to the north, and the Pacific Ocean to the west. Within these two main watersheds are smaller watershed areas including the Lower Nooksack Sub-basin (Nooksack), as well as Drayton Harbor, Birch Bay, and Lummi Bay (Strait of Georgia). The surface waters from each of these watersheds flow from inland areas to the marine, impacting the Puget Sound, as well as various resources, communities, and industries along the way. The Sumas watershed, shown on the map, was not included in the grant focus area, as its surface waters flow north into Canada; however, the area was included in the project because the land use is similar and representative of the county as a whole and the Sumas-Blaine aquifer, which runs from the north in Canada south into the US, is an area of significant resource concern for high nitrates in Whatcom County.

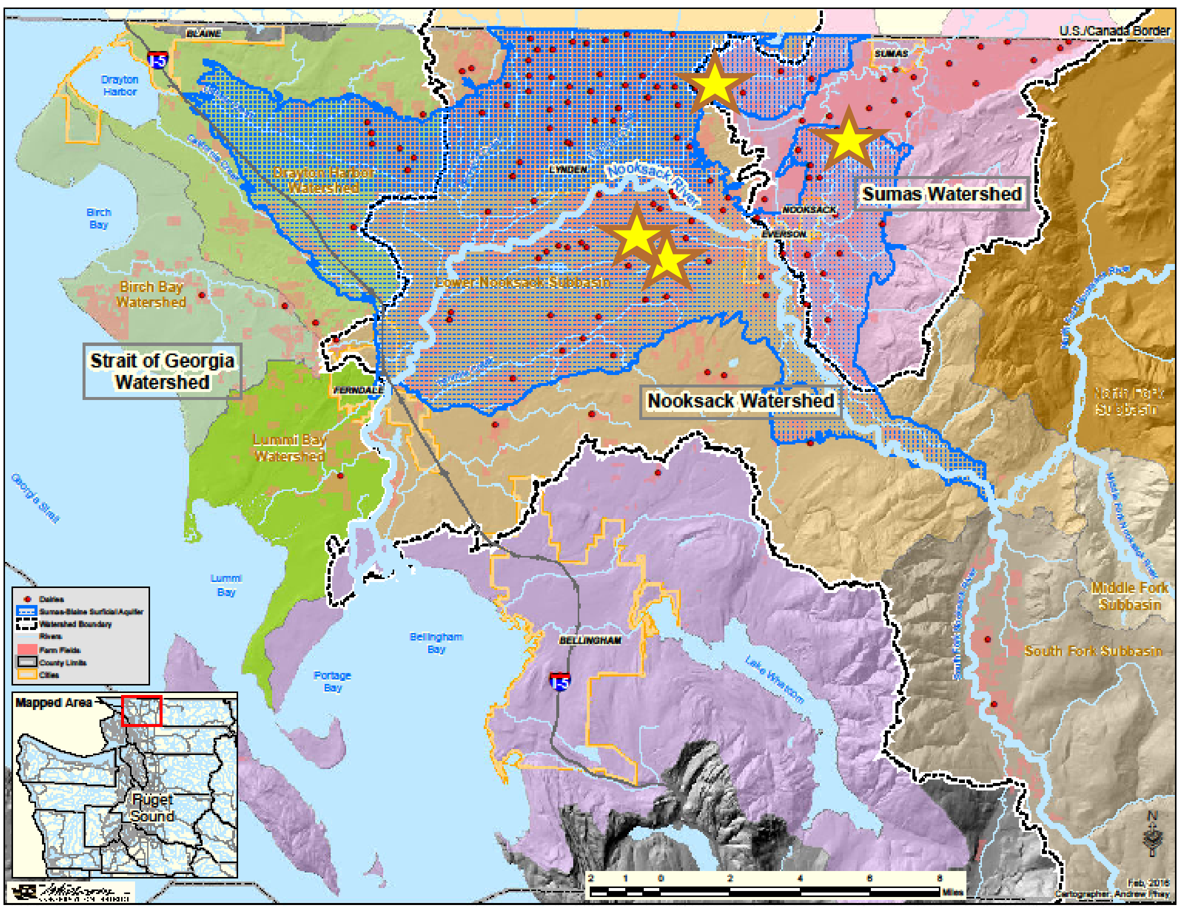


Figure 14.1. Map of study area in Whatcom County, WA. Red dots depict dairies and pink areas represent the land base associated with those dairies. The blue hashed area represents the Sumas-Blain aquifer region. Yellow stars represent areas where test farms were approximately located.

The project was conducted on four paired field sites from 2011-2015. The sites, referred to as A, B, C, and D, were enrolled in the study period for varying lengths of time (Table 14.1). NOTE:

Due to its short time in the project, limited information and results are presented for Site A in this report.

All sites were forage fields (orchard-fescue grass mix) with seasonal manure application, irrigation (B and C), and regular forage harvest. There was water adjacent to only one field (D). All others were located away from waterways to protect against any potential runoff events during the project period. Rainfall at sites varied from 47 and 53 inches per year. Soil type was either sandy (B, C) or silty (A, D).

The sandy soil type was characterized as a very deep, well-drained soil. The top 36 inches are a silt loam with high organic matter and a moderate permeability. Below 36 inches, the soil tends to be gravely or cobbled with a rapid permeability. Runoff is characterized as very slow and erosion very low. The seasonal high water table tends to be no more than 6 feet from the surface in the winter months.

The silty soil type was characterized as a very deep, poorly drained soil. The top layer is a silt or silty clay loam with mottled silt loam beneath. The permeability is moderately slow and a high water table, which is at a depth of 1-3 feet, is present from November through April. Runoff is slow and typically affected by soil saturation and water table depth.

Table 14.1. Site description of four plot sites

Name	Soil Type	Crop Type	Seasonal Rainfall (in)	Dates Enrolled	Reason for Exit
A	Silt	Grass forage	47	10/2011-7/2012	Conversion to berry
B	Sand	Grass forage	47	10/2011-5/2015	End of project (5/15)
C	Sand	Grass forage	53	10/2012-4/2015	End of project (5/15)
D	Silt	Grass forage	48	10/2013-5/2015	End of project (5/15)

All fields had manure application conducted 5-6 times throughout the growing season from January-October. Exact timing depended on treatment and forage harvest timing. Manure application equipment was typically a splash plate drag hose (aerator used occasionally in early spring), but a big gun was used in some early season applications for convenience to the landowner. Forage was harvested from fields at regular seasonal intervals with an average of five cuttings per field per year.

14.2. Experimental Design

A probability-based experimental design was chosen to give a representative view of the target population using a smaller subset of that population. The goal of the sampling program outlined was to monitor trends in environmental conditions based on current and modified practices.

Field and Plot Selection. The experimental sampling design for this project was done in various parts. First, test farms were selected based on interest, farm type, crop type, and field characteristics. Second, test fields were chosen from all fields available at the farm. The field needed to meet the following criteria to be applicable: was currently in forage and would remain so for at least four years, minimum 10 acres in size, all the same soil type, did not have a surface gradient over ~six feet in difference across the field, no ponded or “a-typical” spots in the field, had historical manure application. Third, test locations within the field were selected. The field was split evenly into two equal sized plots, approximately five acres, representing the treatment and control. A labeled grid was overlaid onto each plot with nine primary quadrants and four secondary quadrants within each primary. To select the six sampling sites within each of the treatment and control plots, random selection of six primary grids was chosen, then a selection of one of the four secondary grids within each primary. These 12 sites (six treatment and six control) were the chosen sites of the lysimeter installation and co-located soil sampling. Figure 14.2 shows the final test plots with lysimeters and co-located monitoring wells (see USGS project) for sites B, C, and D.

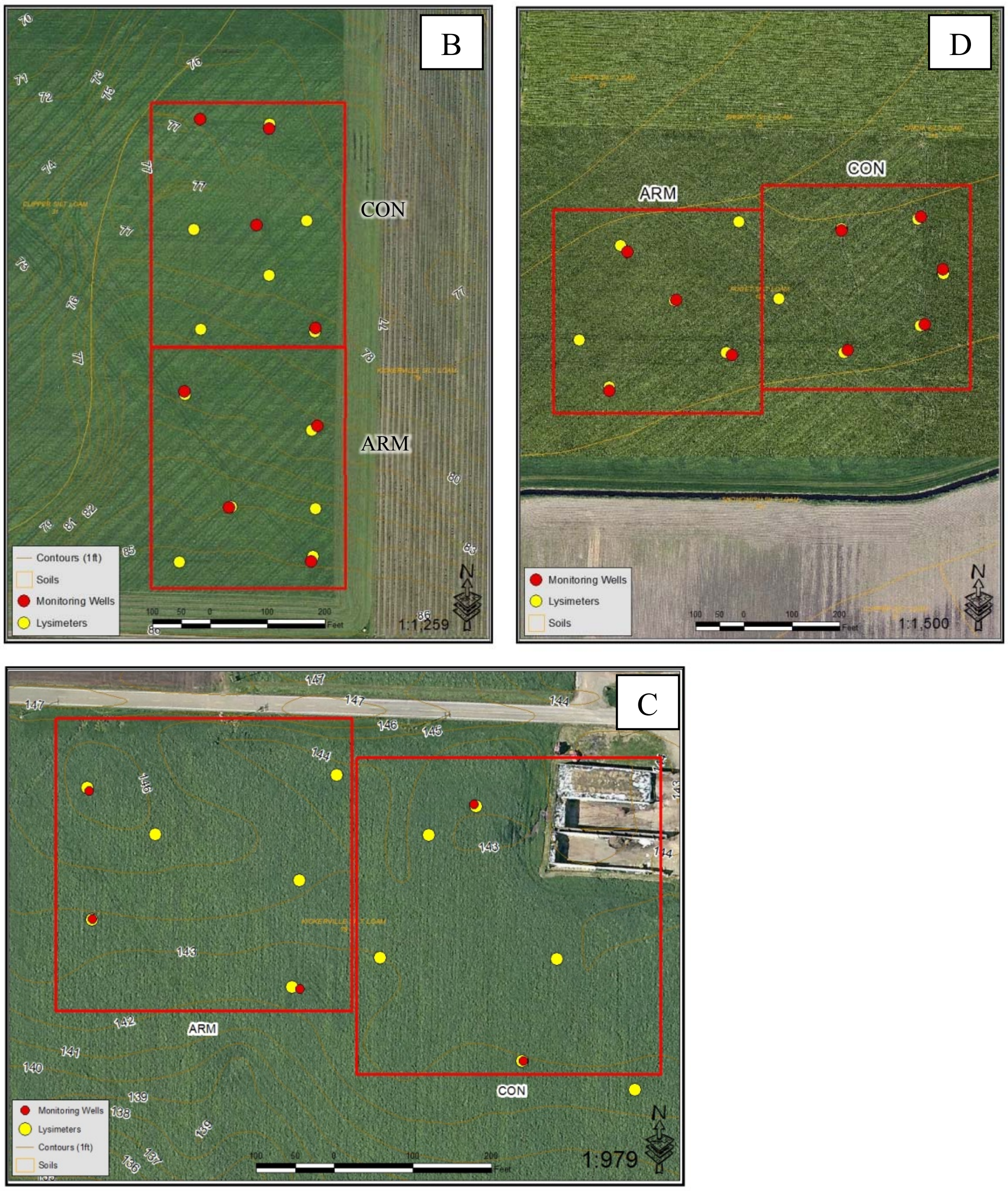


Figure 14.2. Plot locations with lysimeters (yellow dots), monitoring wells (red dots), soil types, and 1 foot contours identified for Sites B, C, and D.

14.3. Treatments

Two paired treatments were evaluated in this study:

1. **CON** - the control being a conventional manure application system. The conventional CON method of manure application was based on the "industry standard" methodology of set application dates of February 15-October 31, minimal consideration of field or weather conditions prior to application, and no calculation of current agronomics rate other than annual need estimation.
2. **ARM** - the treatment being the Application Risk Management system of manure application. The ARM method of manure application used the tools and methodologies presented herein and based application timing on real-time weather and field evaluations as well as soil characteristics and calculated agronomic need.

In the first years of the study just the timing of manure application was addressed. The rate was added on and addressed in subsequent years. This was to be able to determine the effect of manure timing modification with and without consideration of rate to determine if there was a singular verses additive effect.

14.4. In-Field Measurements

The in-field measurement system was designed to look at the partitioning of nutrients within the water, soil, and forage of a manured dairy forage system in Northwest Washington. In order to assess the complex interactions of parameters within the cropping system, and the effect of different manure application strategies on that system, measurement of soil water, surface water, soil, manure, forage, and meteorological parameters was conducted (Figure 14.3).

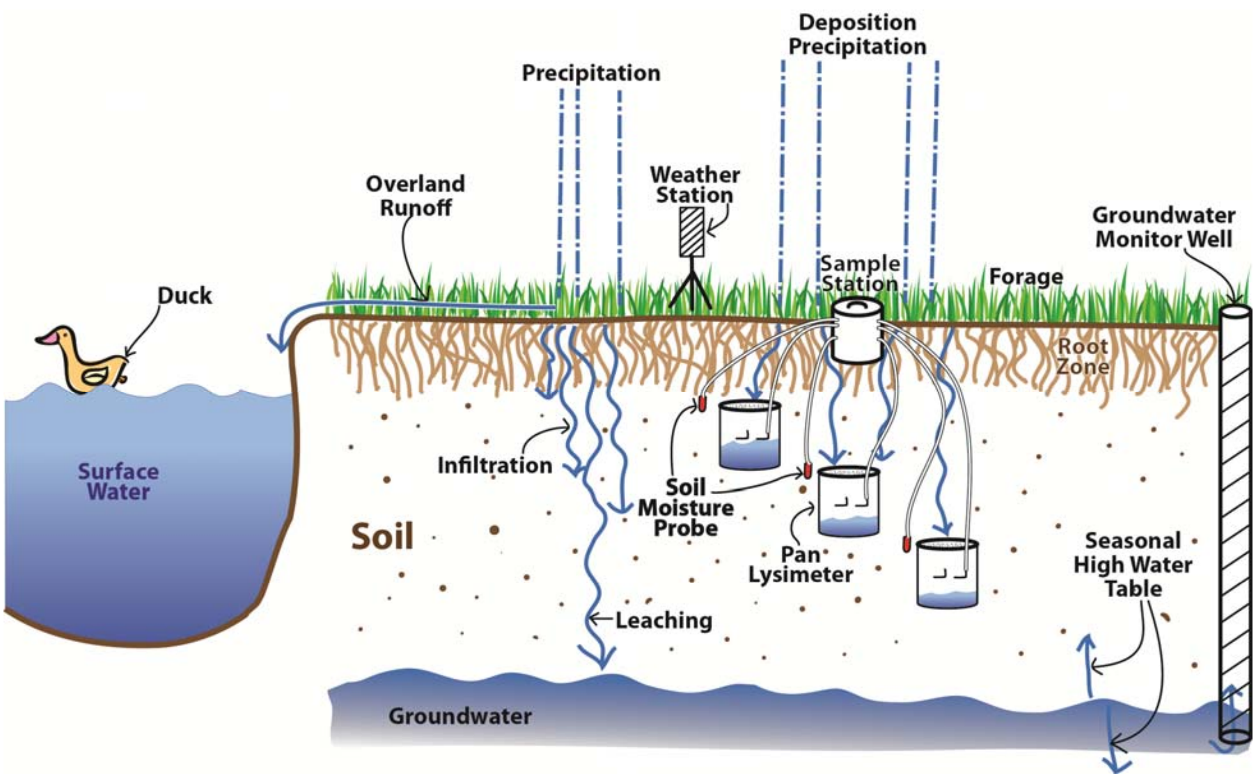


Figure 14.3. Field sampling diagram (not to scale) illustrating location and schematic of field sampling equipment.

A summary of samples and procedures are presented in Table 14.2.

Table 14.2. Standard operating procedures (SOP), and sample collection and storage requirements for mediums and analytes (maximum holding times for water mediums are taken from 40 CFR Part 136; holding times for other mediums are based on laboratory recommendation)

Sample Medium	Analyte	Standard Operating Procedure (SOP)	Container	Sample Storage & Preservation	Holding Time (collection to analysis)
Water (Surface and Soil)	Fecal Coliforms (MTF)	ARM-01-SW1.0 (Soil Water) ARM-02-W1.0 (Surface Water)	120 ml sterile bottle	Ice (4°C ± 2°C) and 0.0008% $Na_2S_2O_3$ if Cl^- present	6 hr at ≤10 °C (EPA)
	Nitrate		250 ml sterile bottle	Ice (4°C ± 2°C)	48 hr at ≤6 °C
	Total Nitrogen			Ice (4°C ± 2°C); acidified with H_2SO_4 to pH<2	28 d at ≤6 °C if acidified with H_2SO_4
	Ammonia N				
	Total Phosphorus				
Soil	Electrical Conductivity	ARM-03-S10	Ziploc sterile plastic bag (1 gal)	Dry, closed container; Ice (4°C ± 2°C)	48 hr at ≤6 °C (dry); or indefinitely at -20 °C
	Organic Matter				
	Total Nitrogen				
	Nitrate				
	Nitrite				
	Ammonia N				
	Total Phosphorus				
	pH				8-24 hours
Manure	Moisture (DM)	ARM-04-M1.0	Ziploc (solid) 250 ml liquid individual or 1 liter bottle for all test	Dry, closed container; Ice (4°C ± 2°C)	48 hr at ≤4 °C; or indefinitely at -20 °C
	Nitrate				
	Total Nitrogen				
	Ammonia N				
	Total Phosphorus				
	pH				
	Total Carbon				
	C:N Ratio				
Forage	Moisture (DM)	ARM-06-F1.0	Ziploc sterile plastic bag (1 gal and 1 qrt)	Dry, closed container; Ice (4°C ± 2°C)	48 hr at ≤6 °C (dry);
	Nitrate				
	Crude Protein N				
	Total Phosphorus				

14.4.1. Surface Water

In-stream surface water was collected from location D only, which had an adjacent waterway. Surface water samples were not taken from fields without adjacent waterways. Samples were collected in a bracketed fashion with an upstream (sampling location background), and downstream (source pollution) sample. The difference of the two measures is the estimated contribution by processes occurring within that field (the field on the other side of the ditch may have some influence as it was up-gradient). A water quality sample was taken 24 hours before and after manure applications as well as significant rain events (>0.50 inches over 24 hours or more). Additional samples were taken as warranted based on weather or field conditions. If the waterway was dry or very low (<10% of normal flow), no samples were taken, but conditions noted. Samples were taken at the same location for each measurement cycle to reduce variability.

Surface water was collected into a 1000 ml sterile bottle using methods outlined by the Department of Ecology (Ward, 2001) and/or the U.S. Geological Survey (USGS, 2006). The bottle was uncapped and inserted into the center of the stream flow to collect the sample. The sample was then split immediately into three labeled sterile bottles provided by the laboratory: a special 120 ml bottle specifically for fecal coliform, a 250 ml bottle sent to the lab, and a 500 ml bottle used for in-field testing with a YSI meter (Pro Plus Multiparameter, YSI). Sample containers were capped immediately, taking care not to touch the lip of the bottle or inside of the cap, and FC and lab samples were placed in a chilled (≤6 °C), UV protected cooler. Fecal coliform and lab samples were taken to the laboratory for analysis the same day (within 6 hours for FC). If same day drop off was not possible, samples were stored in a refrigerator overnight and taken to the laboratory within 24 hours of attainment (fecal coliform analysis were not conducted in this circumstance). Lab samples were analyzed for total nitrogen (ppm), total phosphorous (ppm), nitrate-nitrite (ppm), and ammonia nitrogen (ppm). For the in-field analysis with a YSI probe, a clean field analysis probe was inserted into the 500 ml container for real time analysis of ammonium-N, nitrate, temperature, conductivity, and pH. All results were logged into the meter as well as recorded into a field notebook.

14.4.2. Soil Water

Lysimeters were installed at six locations within each of the CON and ARM plot areas for a total of 12 locations to measure soil water. Exact locations were determined by a randomized grid design over approximately a ten acre area (Figure 14.2).

Improved zero-tension gravitational pan lysimeters (Figure 14.4) were chosen for this study because they are well suited for collection of nitrate, phosphorous, and bacteria concurrently (Weihermuller et al., 2007). Pan lysimeters are passive samplers that collect soil water that has gravitationally percolated through the soil profile and into a filtered collection bucket. The cumulative liquid collected is pumped out of the bucket via tubing and sampled. Pan lysimeters give a description of the cumulative contribution of gravitational soil water through a specific soil profile to a measured depth over a given period of time, and were set at various depths (12, 24, 36 incs) to examine the spatial and temporal transport of nutrients through the soil profile. However, since they can only measure soil water that has naturally flowed through the soil profile, they are only effective with precipitation. Studies have demonstrated that zero tension lysimeters have limitations in collection efficiency in dry soil (Zhu et al., 2002) and non-forage fields (52%: Jemison and Fox, 1992; 48%: Zhu et al., 2002); but perform better during collection under forage fields (Toth et al., 2006), and with the more recent developments in the various types of pan lysimeters (Weihermuller et al., 2007), such as the one used in this study.

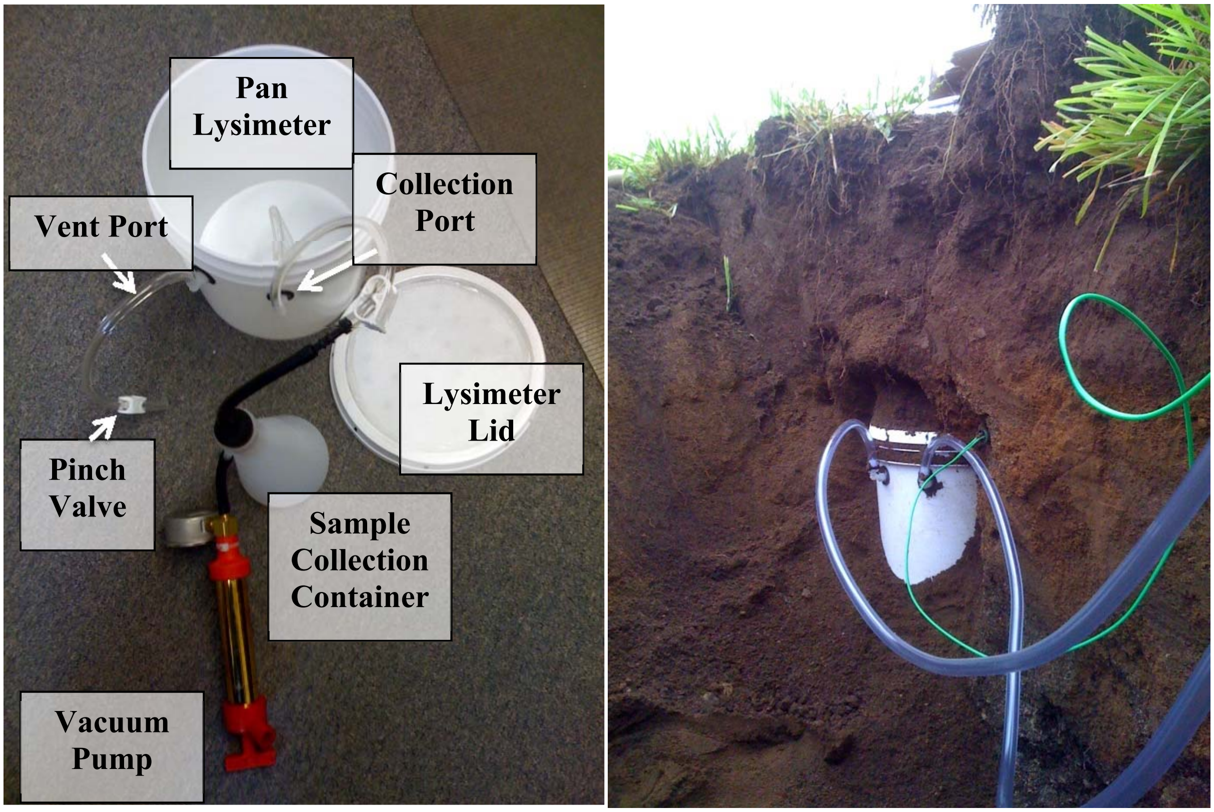


Figure 14.4. Pan lysimeter set-up. The pan lysimeter is a three gal bucket with a modified, felt and polypropylene covered top, and 0.25 inch ports for venting and sample collection (left). Lysimeter installation at 12 inch depth (right).

The lysimeter used in this study (open, zero tension) was designed to collect the gravitational water flowing through the soil pores above the sampler. Water flows from the soil, through the filtered and perforated lid and into a three gallon bucket. The bucket had a vent and collection tube, both of which reach to the surface. Soil water was extracted from the bucket with 0.25 mm Tygon tubing into a measured collection container and volume recorded and compared to precipitation amount and samples transferred to sample containers. The lysimeters were installed on a side cut, leaving undisturbed soil above the pan (Figure 14.5). This was done by excavating a pit and installing the samplers into the exposed area, rather than digging a hole and burying them. During installation, soil depth above and between the pans was measured to ensure a known volume of soil above the pan was recorded for transport calculations. To maintain hydraulic contact with the soil above the pan, the pan lid was covered with a double layer of polypropylene felt fabric and a topped with a one inch layer of inert sand, the combination of which has been shown to support a greater conveyance of water into the lysimeter, rather than around it (Thompson and Scharf, 1994).

Figure 14.5. Installation of three lysimeters at 12, 24, and 36 inches with sample tubing routed into the sample housing (left). Soil profile down to 36 inches prior to installation (right).

Soil water samples were taken 24 hours after precipitation events over 0.25-0.50 inches (a precipitation "event" is a continuous period of precipitation lasting 24 hours [0800 to 0759 h] or less) and/or soil moisture levels at 100%). When the water table was above a lysimeter depth (determined by observing monitoring wells), a sample was taken immediately after the depth reached the pan top and has receded below the pan (site D only). These samples will be marked as such and used for observational purposes.

Soil water was collected using a hand pump and into a sterile collection vessel. The total volume of water collected was noted for each depth and location. A sub-sample (if applicable) was transferred from the collection vessel into 250 ml sterile environmental testing bottles provided by the laboratory. The sample was capped immediately, taking care not to touch the lip of the bottle or inside of the cap, and placed in a chilled (≤6 °C), UV protected cooler. Samples were taken to the lab within 12 hours of sampling. If they were not able to be taken to the lab within the specified time (<5% of total samples), they were frozen and taken at a later date. In the case of low collection volumes (<25 ml) where all analytes could not be analyzed, an analysis priority was initiated. Samples were analyzed, in preferential order, for nitrate (ppm), total nitrogen (ppm), ammonia-N (ppm), total phosphorous (ppm), and pH.

14.4.3. Soil

Soil Sample. Soil samples were taken at least monthly at semi-randomized times. This means that care was taken to avoid sampling just after a manure spreading event which could bias samples in upper horizons, as well as significant rain events that introduced a higher rate of error in the sampling process. Additionally weekends and holidays were excluded due to labor availability. Sampling events tended to occur near the end of the month.

Soil sample locations were co-located near lysimeters to assist in comparison of soil and soil water parameters. Soil samples were taken within a six to ten foot radius from the lysimeter plots to avoid creating direct channels to lysimeters, but also remain representative of the sample plot. Locations were noted so that they were never accidentally re-sampled. Soil core holes were filled in with appropriate horizon soil not sent to the lab. This was to further minimize any pores or channels from the surface of the field.

Twelve soil samples were taken in each test field, six in the CON plot and six in the ARM plot. Each of the twelve samples was analyzed separately to explore variability within plot areas. Soil samples were taken at three depth segments (0-12, 12-24, and 24-36 inches) using a clean and dry soil push probe (12 inch sample length, 1 inch diameter) or auger (12 inch sample length, 2.75 inch diameter, AMS) (Figure 14.6). Push probes were used early in the project but replaced with more durable augers mid-way through the project. Individual soil cores were extracted and placed into the appropriate bucket. The sample was mixed thoroughly using a gloved hand and a 500 gram homogeneous sub-sample of each segment was transferred into a clean, labeled bag provided by the lab. A second 100 gram sample was also collected into a separate bag for in-house soil moisture analysis. Samples were stored and transported to the lab in a chilled (<10 °C), closed container within 12 hours of sampling. Soil samples were analyzed for total nitrogen (ppm), nitrate (ppm), ammonium-N (ppm), total Bray phosphorous (P1 and P2) (ppm), electrical conductivity (Umhos/cm), OM (%), and pH.

Figure 14.6. Soil sampling with auger at 12 inch depth (left). Soil thermometers at 12 and 24 inch depths (right).

Soil Temperature. Soil temperature (F) was determined at 12 and 24 inches using a hand held probe thermometer (36 inch length, Compost Thermometer, ReoTemp) (Figure 14.6). Temperature at 36 inches was not taken as it was often times too difficult to get the probe that deep due to soil profile characteristics. Early determination of soil temperature did not reveal a significant difference between the soil temperature at the 24 and 36 inch depths.

Soil temperature was determined at a representative location within the field at each soil sampling and/or lysimeter sampling event. Soil temperature measuring events tended to occur between 0900 and 1300 hours. It was determined early on by measurement that the soil temperature was consistent (within 1 degree) across the field and thus only needed to be taken at one location to be representative of the whole test area.

Soil Moisture. Soil moisture was determined by resistance (gypsum) block (Soil Sensor, Watermark) and/or soil drying technique. Early in the project, gypsum blocks were installed at sites A and B at the same time as lysimeter establishment at each of the 12, 24 and 36 inch lysimeter depths in all sample 12 plots. The gypsum blocks were analyzed at each lysimeter sampling event by connecting the block electrodes to a handheld monitor and the reading recorded in a field log book. Resistance gypsum blocks work by absorbing water into the gypsum, which is cast around two electrodes, dissolving some of the gypsum and effectively lowering the resistance for an electrical current to be passed between the two electrodes. The more water that enters the gypsum block, the lower the resistance. Once installed, gypsum blocks were left in the soil for the entire life of the project. Unfortunately, we had many challenges with the gypsum blocks working consistently. In response, we moved to a more accurate and reliable method of soil moisture analysis. At each soil sampling event (see above), we took an additional sample that was processed for analysis in-house within one hour of sampling. Each of the samples was wet weighed, dried using the microwave oven technique (Gay et al., 2009), dry weighed, and soil moisture or DM (%) calculated (see SOP for details). The DM was determined by $DM(\%) = (W_{wet} - W_{dry})/W_{dry} * 100\%$, where W_{wet} is the wet weight (g) and W_{dry} is the dry weight (g) of the soil.

14.4.4. Manure

Manure application data was collected from the landowner for each application to the test areas including date of application and application rate (gal/acre). The landowner also provided results of manure analysis taken by their consultant. Parameters measured by laboratory analysis included ammonia-N (ppm or lbs/1000gal), total nitrogen (ppm or lbs/1000gal), total phosphorous (ppm or lbs/1000gal), and potassium (ppm or lbs/1000gal). In some instances, the analysis was done in-field using an Agros Nova Meter (Agros, Sweden) which only provides total nitrogen and ammonium-N in lbs N/1000gal. Additional manure tests were taken for validation of producer's results as well as calibration of equipment from both the lagoon and in the field from the application equipment.

For samples taken from the manure lagoon, the lagoon was agitated to better homogenize the manure and 3 to 5 samples were taken using a 10 foot pole at the edge of the lagoon (Dou et al., 2001) and composited for analysis (Figure 14.7). For in-field samples taken during manure application, clean buckets were placed on the ground and manure was collected as the application equipment (drag hose, splash plate) passed by releasing manure onto the field (Figure 14.7). Using this method, the manure was composited into a graduated cylinder and volume used in conjunction with known area to determine the application rate. This technique was also used to calibrate equipment (Jokela, 2004) and determine the manure application rate (Downing, 2013). All collected samples were transferred into a 500 ml sterile plastic sample container, and stored and transported in a chilled (≤6 °C) cooler. Samples were taken to the laboratory within 12 hours of collection. If samples could not be taken same day to the laboratory, they were frozen at -20 °C until transported to the lab. This was less than 10% of total samples. All manure samples were analyzed for DM (%), pH, electrical conductivity (mmhos/cm), OM (%), ammonia (ppm), potassium (ppm), phosphorous (ppm), total nitrogen (%), nitrate-N (ppm), and C:N.

Figure 14.7. Manure sampling from a lagoon (left) and in-field from a splash-plate applicator (right).

14.4.5. Crop/Forage

Forage samples were obtained within 24 hours of each harvest/cutting using the box-and-cut method (Figure 14.8). A PVC frame measuring 12x12 inches was created to obtain a uniform forage sample. The frame was tossed randomly into each of the six CON or six ARM plot areas within the test field. Forage within the frame was first measured for height with a tape measure, then cut by hand at approximately the same height as the harvesting equipment (3 inches), placed in a known weight bag, weighed with a hanging tube spring scale (Accu-Weigh T-10, Yamato), and then transferred into a large composite bag for either the CON or ARM plot. The forage in each composite sample was cut into 2-4 inch segments, mixed thoroughly, and subsampled into two bags which went to the lab for analysis. Samples were stored dry in a dry container and transported chilled (≤6 °C) to the lab within 12 hours. The forage was analyzed by the lab for total nitrogen (%), nitrate (ppm), crude protein (CP) (%) (determined by equation: CP = %N * 6.25), and total phosphorous (ppm). A subsample from each bag was also processed in-house within one hour for dry matter (DM) (%). The DM content of the forage sample was determined in-house using the microwave oven technique (Gay et al., 2009).

The forage total yield (Y) in lbs/acre was measured by $Y = (Y_{wet} \text{ x } DM)/Area$, where Y_{wet} is the wet weight of the forage harvested in the field (lb), DM is the dry matter determination in-house (%), and $Area$ is the total area of the sample frame (acre). This was determined separately for CON and ARM and compared on a percent difference basis for each cutting.

Figure 14.8. Forage sampling PVC "hoop". Forage was hand cut down to mowing height of approximately three inches (left). Forage was measured prior to cutting with a tape measure (right).

14.4.6. Meteorological

The most relevant meteorological parameter impacting the project outcomes was precipitation. Due to challenges with daily retrieval and location, on-site precipitation gauges were not installed. Rather, long-term sites were used including Washington State University's (WSU) AgWeatherNet site at Ten Mile, and the NOAA station at Clearbrook. Parameters were recorded in real time and logged hourly or daily. Parameters logged at the WSU site included precipitation (in), ambient temperature (°F), humidity (%), dewpoint (°F), wind speed (mph), solar radiation (MJ/m^2), leaf wetness (u), and 8" soil temperature (°F). Parameters logged at the Clearbrook station included precipitation (in), snowfall (in), and ambient temperature (°F).

- WSU Ten Mile station accessed at: http://weather.wsu.edu/?p=88650
- NOAA Clearbrook Station accessed at: http://www.lutheransonline.com/servlet/lo_ProcServ/dbpage=page&ctoken=UoMuCwaG&gid=20121538496019562301111555

The four-day precipitation forecast was recorded daily from NOAA. From 2010-2012 the precipitation forecast data was manually recorded in Excel from a central site in Lynden, WA. From 2012-2015, the forecast data was automatically recorded through the MSA and was specific to project site locations. Additional forecast sites were selected that had verifiable precipitation data such as the WSU Ten Mile and NOAA Clearbrook stations, as well as the Bellingham airport. This was done for validation of the MSA forecast verses actual precipitation.

- NOAA forecast (Lynden, WA) accessed at: http://www.wrh.noaa.gov/forecast/wxtables/index.php?lat=48.96489222788762&lon=-122.44949340820312&table=custom&duration=7&interval=6

14.5. Statistical Analysis

A variety of statistical analyses were utilized to analyze the data collected. All statistical significance was evaluated at an alpha level of 0.05 ($p < 0.05$). A trend was evaluated at an alpha level of 0.10 ($p < 0.10$).

Basic descriptive statistics (i.e., mean, standard deviation, standard error, variance, count) using Excel were used to provide description of all data sets and treatments as appropriate (Excel, Microsoft, 2010).

A t-test analysis was used for comparison of the mean to a value (one-sample) or between two sample means (two-sample) when data sets were normally distributed and this analysis was appropriate (Excel or R).

The ANOVA analysis was utilized to analyze difference between two or more independent variables/groups and determine if there are statistically significant differences between and/or within groups. The one-way ANOVA analysis was used most commonly to determine if there was an overall effect of various levels of an independent variable (a standalone variable that is not influenced by the study) on a dependent variable (value that represents an outcome of the study). A two-way ANOVA analysis was used for those data sets where we wanted to determine if there was an interaction between two independent variables on a dependent variable.

Correlation between two variables was assessed using linear regression in which the predictiveness of two variables was assessed and the coefficient of determination (how closely one value is predicted by another) presented.

The individual test used for each of the variables measured is indicated in the results section of each parameter.

14.6. Results and Discussion

14.6.1. Forage

Forage growth was analyzed by treatment within site for yield and height using the t-test analysis (Table 14.3). The ARM treatment had greater forage yield in the spring (March-May) than the CON treatment at sites B and C ($p < 0.10$), which were similar soil type (“sand”). When actually grouped and compared by soil type and treatment, ARM had higher yields at a greater level of significance ($p = 0.03$) (Figure 14.9).

When analyzed for forage height, there was no significant difference between treatments at the B and C sites in the spring. This denotes that the greater yield was likely due to increased density of the forage, rather than height. This is a good observation as a greater density of forage will increase sediment trapping, water infiltration, and generally have a positive impact of surface water pollution reduction. The silt soil type showed similar patterns in the spring, but due to the low number of sample points (n = 1), no statistical comparison could be run. Therefore, all results are reported as trends for the “silt” soil type.

Table 14.3. Forage yield and height statistical data (SE = standard error of the mean, n = number of observations) by site, season, and treatment

Measure	Site	ARM Mean	ARM SE	CON Mean	CON SE	n	p-value (α = 0.05)
All yield data (ton/acre)	B	1.81	0.17	1.66	0.09	11	0.20
	C	1.67	0.18	1.58	1.58	10	0.82
	D	2.17	0.36	1.89	0.15	5	0.30
Spring yield (ton/acre)	B	2.12	0.26	1.63	0.16	4	**0.06**
	C	2.22	0.28	1.81	0.09	3	**0.09**
	D	2.55	0.95	1.6	0.27	2	0.30
Summer yield (ton/acre)	B	1.64	0.32	1.84	0.11	4	0.31
	C	1.45	0.25	1.52	0.24	5	0.31
	D	2.13	0.06	2.13	0.11	2	0.24
Fall yield (ton/acre)	B	1.61	0.24	1.46	0.17	3	0.22
	C	1.41	0.70	1.42	0.002	2	0.45
	D	1.48	NA	1.97	NA	1	NA
All height data (in)	B	23.47	1.00	22.56	1.49	11	0.10
	C	23.47	1.35	23.91	1.48	10	0.22
	D	22.23	0.90	21.67	0.49	5	0.34
Spring height (in)	B	24.46	2.33	23.29	3.65	4	0.25
	C	29.09	0.55	29.96	2.31	3	0.34
	D	23.91	0.25	21.37	0.83	2	0.10
Summer/Fall height (in)	B	22.90	0.97	22.14	1.38	7	0.16
	C	21.07	0.83	21.41	0.56	4	0.29
	D	21.10	1.06	22.33	0.17	3	0.15

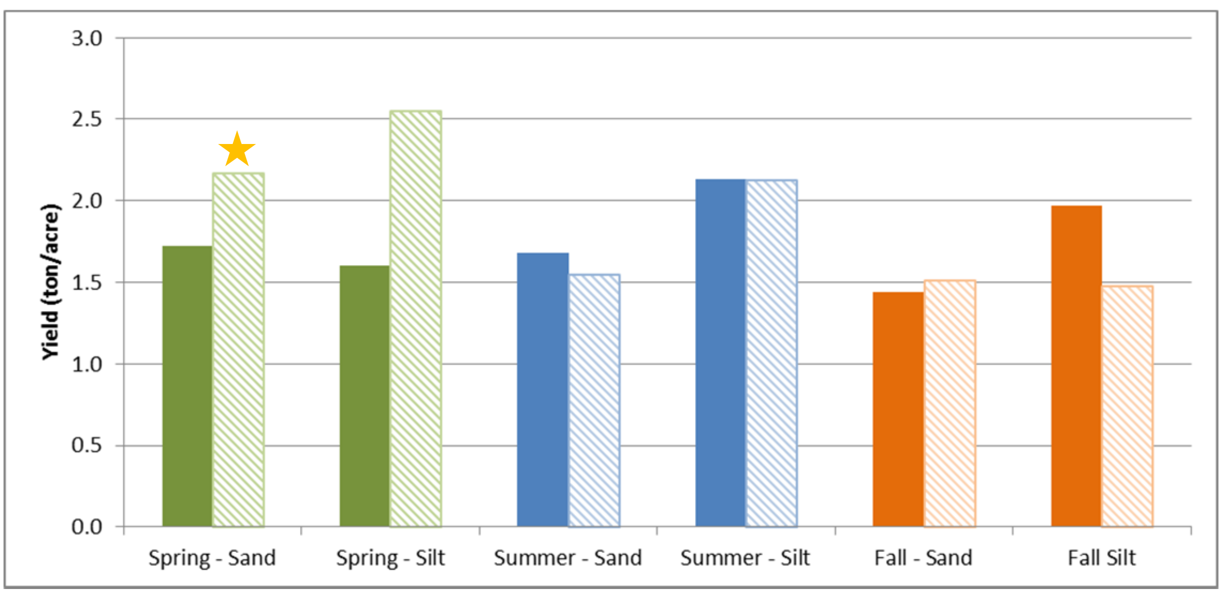


Figure 14.9. Forage yield (dry ton/acre) by soil type and treatment. CON is solid bars, ARM is hashed bars. Stars denote significant differences at p = 0.05.

Forage nutrient levels were measured to determine if manure application timing had any impact on forage quality in addition to yield. In general, there were no statistical differences between treatments for nutrient values (Table 14.4). The one exception was for site D, which had significantly higher crude protein levels in CON for all seasons ($p < 0.05$). This could be due to the "silt" soil type and ground saturation in part of the field which effected crop uptake.

Table 14.4. Forage nutrient (NO3 = nitrate (ppm), CP = crude protein (%)) statistics (SE = standard error of the mean, n = number of observations) by site, treatment, and season

Measure	Site	ARM Mean	ARM SE	CON Mean	CON SE	n	p-value (α = 0.05)
NO3 All data (ppm)	B	2007.17	500.82	1973.49	423.26	11	0.46
	C	2101.8	307.7	2207.4	339.6	10	0.35
	D	1288.0	343.9	1307.6	1307.6	5	0.48
NO3 Spring (ppm)	B	1923.27	1268.64	1368.11	635.35	4	0.23
	C	1693.3	430.6	1778.5	727.5	4	0.43
	D	840.0	358.9	1056.0	1056.0	3	0.35
NO3 Summer/Fall (ppm)	B	2055.11	442.72	2319.42	546.82	7	0.26
	C	2374.2	415.6	2193.3	305.6	6	0.38
	D	1960.0	208.0	1685.0	224.0	2	0.32
CP All data (%)	B	20.16	1.2	20.13	0.91	11	0.48
	C	20.00	0.91	19.76	0.86	10	0.36
	D	17.59	1.45	19.11	1.24	5	**0.02**
CP Spring (%)	B	20.08	2.63	19.16	2.04	4	0.27
	C	19.98	0.89	19.33	1.37	4	0.26
	D	17.31	2.26	19.19	1.81	3	**0.05**
CP Summer/Fall (%)	B	20.21	1.34	20.68	0.9	7	0.31
	C	20.01	1.47	20.05	1.19	6	0.48
	D	18.00	2.31	18.72	2.34	2	**0.01**

14.6.2. Manure

14.6.2.1. Manure Analysis

Manure nutrient levels differed by site and changed throughout the year based on the concertation per unit of volume (lb/1000 gal), which was influenced by rain/water dilution (Table 14.5). At Site B, the lowest nutrient concentration per unit of volume occurred in the late fall which was significantly lower than the highest value seen in the summer ($p < 0.001$). This is because the site had a good amount of clean water catchment that diluted the manure concentration during the rainy months, and a multiple stage lagoon which allowed transfer and selective dilution throughout the year. This can be seen in the dry matter values which indicate the relative dilution of the manure (the higher the number, the less water diluting the manure) and are highly correlated to the total N ($R^2 = 0.81$) and total P ($R^2 = 0.93$) values. The same strong seasonal differences were not seen at Site C where the total nitrogen values did not significantly vary throughout the year ($p = 0.84$) indicating that they had good clean water management and little catchment and dilution into their lagoon. Site C also showed the same strong correlations between dry matter and total N ($R^2 = 0.81$) and total P ($R^2 = 0.79$). This data shows that it is important to measure the manure concertation per unit of volume on a per site basis throughout the year prior to manure application so that accurate concentrations and volumes are applied to meet crop needs.

Table 14.5. Average manure nutrient content at Site B and C by season for total nitrogen (Total N), ammonia-N (NH3), total phosphorous (Total P), and potassium (K) in pounds per 1000 gallons (lb/1000gal) and dry matter (DM %) and pH

Site B Season	Total N (lb/1000 gal)	NH3 (lbs/1000gal)	Total P (lbs/1000gal)	K (lbs/1000gal)	DM (%)	pH
Fall	8.20	6.07	0.75	6.62	0.87	7.79
Winter	12.81	5.62	1.79	4.59	2.09	7.58
Spring	11.71	4.56	1.58	5.53	1.80	7.58
Summer	20.73	4.51	4.30	7.77	3.71	7.44
Site C Season	**Total N (lb/1000 gal)**	**NH3 (lbs/1000gal)**	**Total P (lbs/1000gal)**	**K (lbs/1000gal)**	**DM (%)**	**pH**
Fall	15.51	7.86	2.90	10.49	2.48	7.26
Winter	16.90	9.46	2.44	9.29	2.44	7.65
Spring	17.93	9.41	2.69	12.45	2.93	7.26
Summer	17.03	7.44	2.69	11.80	2.63	7.23

14.6.2.2. Manure Agronomic Rates and Application Schedule

Agronomic Manure Application. While the ARM system focuses on proper application timing, the application amount can have effects on nutrient cycling in the agronomic (soil, crop, manure) system. If too much nutrient is applied, we expect to see it leach through the soil profile and eventually to the soil and groundwater, or potentially runoff; too little and we expect to see crop declines and low N levels in the forage and soil profile. Therefore, it was suggested that producers apply at agronomic rate which is the amount of nutrient needed by a crop at any given time minus the nutrients currently available in soil. Because manure has a lag time from application to availability, it can be hard to deliver the exact amount when needed. Therefore, the annual crop need is calculated by estimating the annual crop yield and dividing by application events. For instance, for Site B, which had an annual yield total of approximately 7 ton/acre forage at 20% crude protein, we used University guidelines that recommend a total annual nitrogen application amount of 448 N lb/acre (64 lbsN per ton of dry matter removed) (Downing, 2007). Since a 20% “loss” of nitrogen is expected as it is volatilized, mineralized, and/or immobilized in the soil, the actual application rate was closer to 537 lbN/acre. Divided among the expected 6 application events and 5 cuttings per year (application is typically done once before first cutting if possible, and after every subsequent cutting), that was approximately 90 lbsN/acre/application. The manure test N for each time of year was then used to calculate the application rate (gal/acre) for each application event. For example, if the manure test total-N was 15 lbs/1000gal, then the producer would apply manure at a rate of 6,000 gal/acre. However, data shows that the first couple of forage cuttings had a higher yield, and thus need a greater nutrient application rate to meet crop needs. Based on those findings, to meet an annual N need of 537 lbN/acre, the recommended application schedule was 120/120/120/90/90/60 lbN/acre for the 6 manure application events. Using the manure tests from Site D (Table 14.5), the application rates were approximately 9,368/10,248/10,248/4,341/4,341/7,317 gal/acre. A similar exercise was performed for each of the other sites. The difference with Site D was that the soil type didn’t permit application until late February or April, depending on the soil moisture and crop growth. This means that that Site had one fewer manure application event.

One aspect of manure is that the nitrogen fraction is composed of approximately 50% organic nitrogen and 50% ammonia-nitrogen, and contains little to no nitrate. This means that the manure N has to convert in the soil to plant available nitrate via the nitrogen cycle. Because of the influencing factors on manure conversation rate such as soil temperature, soil moisture, and soil microbial community, it is hard to predict the exact rate and timing in which manure N will be available to a plant. Additionally, it is difficult to predict annual weather events which can influence crop growth and nutrient movement via ambient temperature and/or precipitation. This can lead to unexpected nutrient surpluses, or deficits, at the end of the crop year. Unfortunately, this is also the most sensitive time for nutrient transport through the soil profile, particularly in sandy soils, as our data demonstrates.

Manure Application Schedule. The general manure application schedules for the CON and ARM treatments for Site B, C, and D are listed below. The exact dates are not given, as they vary annually based on soil and weather conditions. However, the general pattern and month is relatively constant.

General application schedule, Site B and D (“sand” soil):

- ARM: January, February/March, April, June, August, September
- CON: February/March, April, June, August, September, October

General application schedule, Site C (“silt” soil):

- ARM: March/April, May, June, August, September
- CON: March/April, May, June, August, September, October

The primary difference in the two treatments, CON and ARM, at Site B and D is the first and last application event. For the ARM treatment, the first application was in January rather than February or early March, which means that there was more time for manure to convert and become plant available as grass growth spiked. Conversely, the final application was in September in ARM, verses late October in CON, reducing the amount of N that was put out late season and available for fall leaching if not taken up by forage, which was declining in growth in the fall. In both scenarios, the same amount of total N was applied, just at different times of the year. At Site D, the application events started at the same time in CON and ARM in March or April when soils and weather permitted, and had a similar growing season application schedule, until the last application event, which ceased in September in ARM and October in CON. Results of each manure application scenario by parameter are presented.

14.6.3. Soil

14.6.3.1. Soil Temperature

Soil temperature was significantly different between seasons for both the 12 ($p < 0.001$) and 24 inch ($p < 0.001$) soil depths (Table 14.6), except for the spring and fall which exhibited non-significant means for both the 12 inch ($p = 0.41$) and 24 inch ($p = 0.18$) depths. While the soil temperature tended to be lower at the 24 inch depth, soil temperature was not significantly different between the 12 and 24 inch depths across all seasons (12in $\mu = 49.1$; 24 in $\mu = 50.6$; $p = 0.12$).

Table 14.6. Soil temperature data pooled for all sites with ANOVA p-value

Depth	Season	Mean	Variance	n	Significance[1]	p-value[2]
12 inch	Winter	40.2	31.8	57	A	**$5.89\text{x}10^{-26}$**
	Spring	51.8	99.9	22	B	
	Summer	66.9	15.6	20	C	
	Fall	51.2	92.3	49	B	
24 inch	Winter	42.4	8.57	57	X	**$1.39\text{x}10^{-35}$**
	Spring	52.2	49.30	22	Y	
	Summer	63.9	11.04	20	Z	
	Fall	53.8	40.97	49	Y	

[1] Parameters with the same letter are not significantly different from each other.
[2] p-value represents the significance at $\alpha = 0.05$ for the variance between all four seasonal groups.

The seasonal soil temperature flux pattern was similar for all project sites (Figure 14.10). Sites B and C, which are the same "sand" soil type, had the longest temperature range and show multiple years of the same pattern of soil temperature flux. Site A was only in the project for a few months, and thus the data is not easily compared with other sites. Sites showed a peak temperature in July and low temperature in January at all sites. Soil temperature tended to stay below 40 ºF, the critical value for N conversion, from approximately December through February with some variation between years based on seasonal ambient temperature.

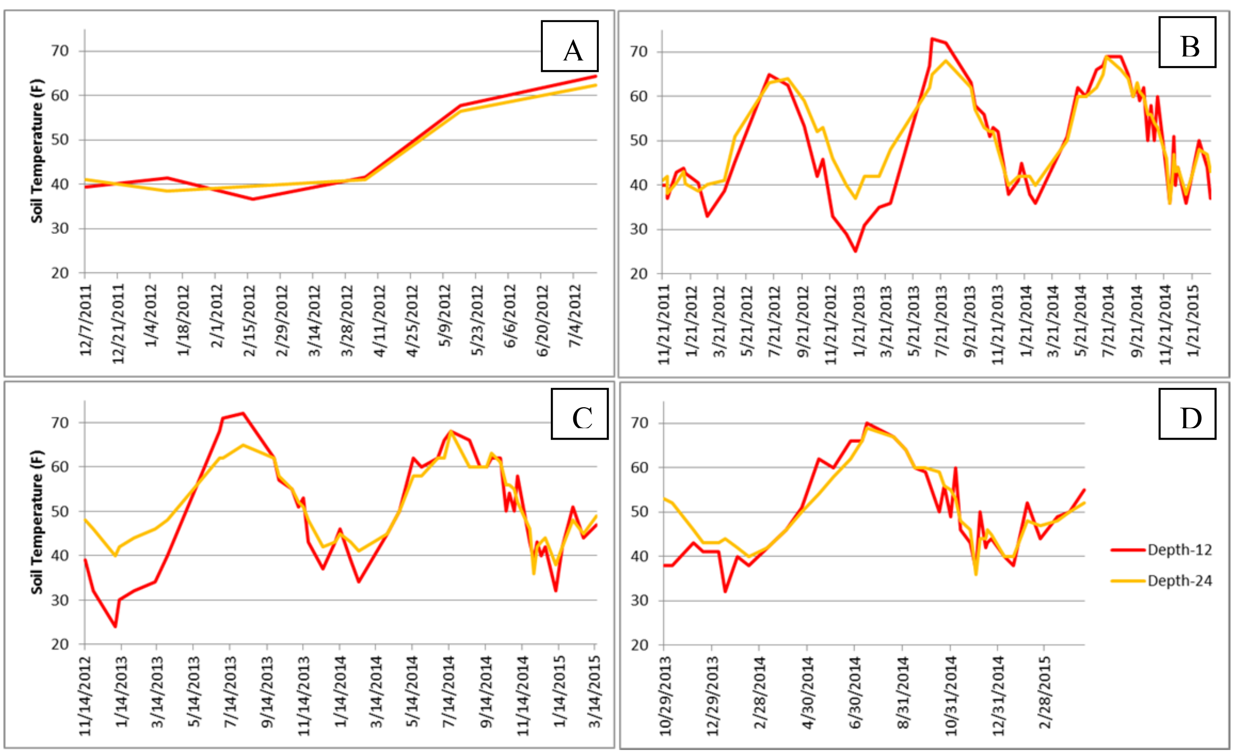


Figure 14.10. Soil temperature for Sites A, B, C, and D. Soil temperature (F) was presented for two depths 12 inch (red line) and 24 inch (yellow line). Each site has a different time scale depending on when it was enrolled in and decommissioned from the project.

The soil temperature tended to be highly correlated to the ambient air temperature for both the 12 inch (R^2 = 0.63) and 24 inch (R^2 = 0.72) soil depths (Figure 14.11). The 12 inch depth tended to have slightly more variability in temperature because of its shallower depth which was more influenced by the varying changes in daily ambient temperature. The 24 inch depth was more insulted and tended to have less daily variability, and thus be more correlated to annual seasonal temperatures.

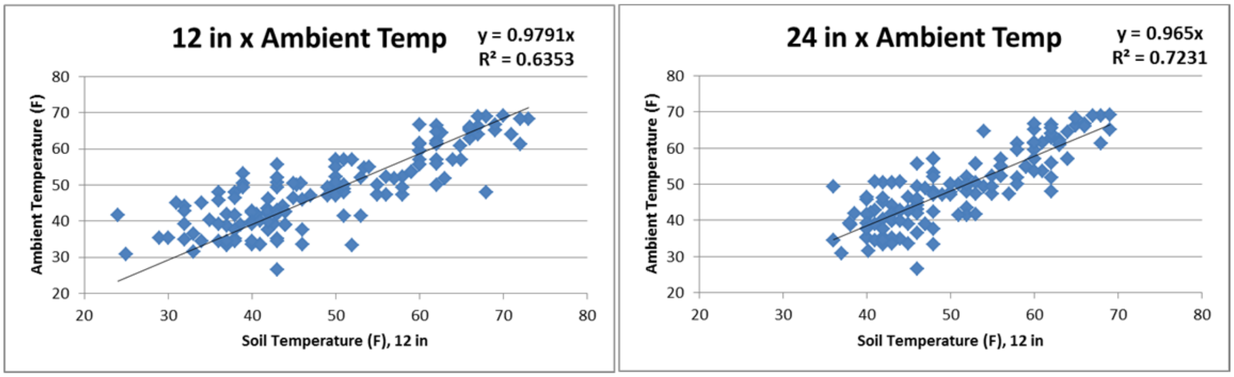


Figure 14.11. Correlation between soil temperature (F), 12 in and 24 in, and ambient air temperature (F).

14.6.3.2. Soil Moisture

The soil dry matter, (%) which is the dry percentage of the soil and when subtracted from 100% moisture will give soil moisture water content, showed similar annual patterns at all sites (Figure 14.12). In general, the 36 inch depth had the lowest soil moisture level, while the 12 inch the highest. This was not surprising at sites B and C which had a similar soil profile with a sand and gravel layer at the 36 inch depth which did not have a good water holding capacity, and thus a low soil moisture or high dry matter %. The 12 inch level showed the lowest soil moisture level in the summer (June-August) at all sites, even sites B and C which had summer irrigation events, which can only be seen as small spikes in soil moisture levels. This is very apparent in 2014, which was a drought year with higher ambient and soil temperatures. A general wetting of the soil at all levels was seen in the fall when seasonal precipitation events started in October. The overall depth differences and trends at Site D were less pronounced due to the silt soil type which had a higher water holding capacity and no sand/gravel layer at 36 inches. The soil profile tended to be more uniform down to 36 inches at Site D and also saturated with the water table during the winter months. This means that no soil sample was taken at those saturated layers, and thus no soil moisture data is available for some winter months.

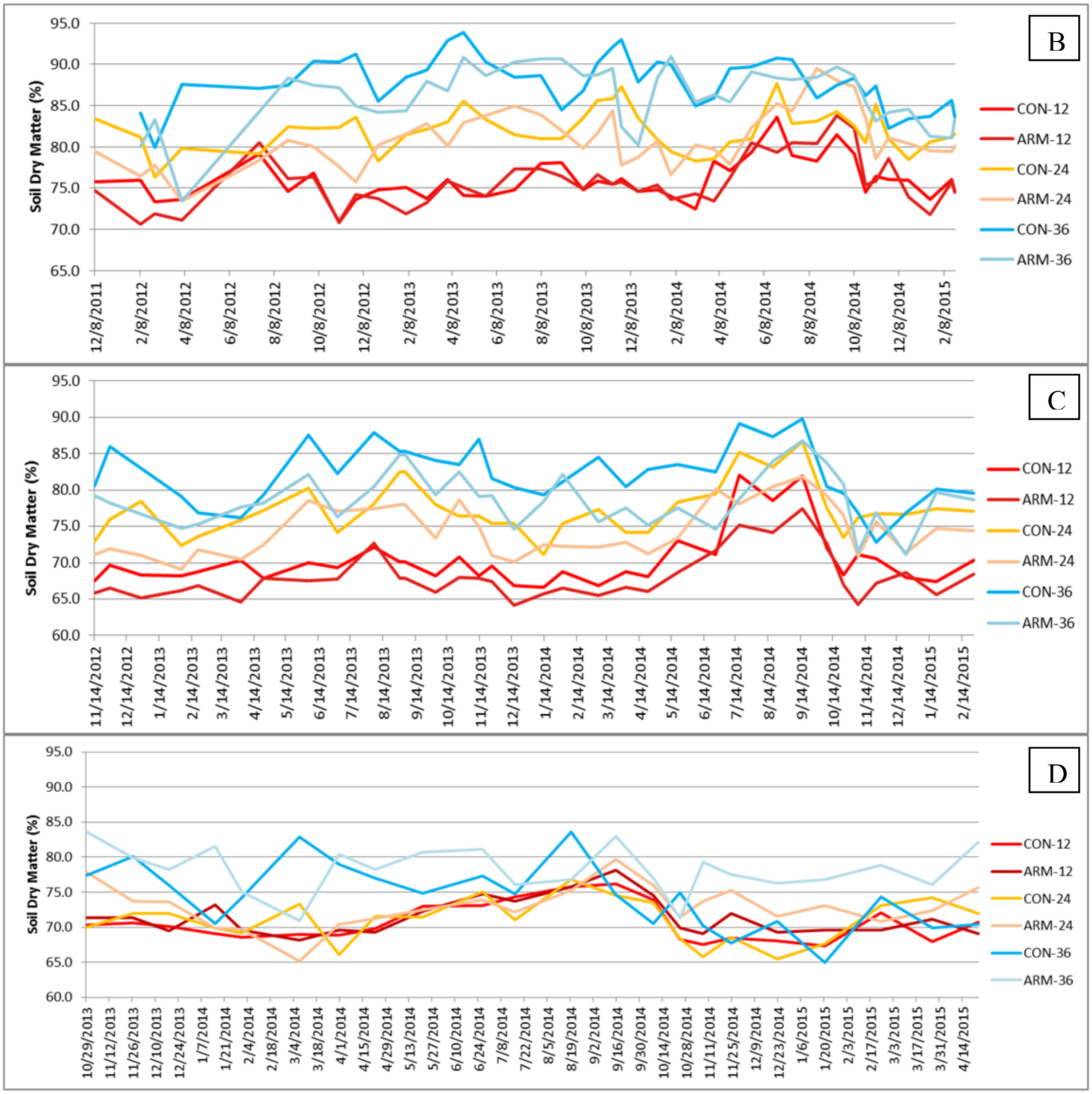


Figure 14.12. Soil dry matter (%) levels for sites B, C, and D by treatment (CON and ARM), and depth (12 = 12 inch, 24 = 24 inch, 36 = 36 inch). All sites had different date ranges due to enrollment and decommission from the project.

14.6.3.3. Soil Nutrients

Soil nutrients varied annually and by site depending on soil type, historical and seasonal manure application, and crop growth and uptake. The “raw” data graphs showing the different soil parameters measured are presented for each site individually for comparison of treatment by depth and date (Figure 14.13, Figure 14.14, Figure 14.15). In general, nitrate was the most seasonally variable and mobile through the soil profile.

Figure 14.13. Soil nutrient "raw" data for Site B for each treatment (Con and ARM) and soil depth (12 = 12 inch, 24 = 24 inch, 36 = 36 inch). Data presented on the left axis includes total phosphorous (bray P1and P2, ppm). Data presented on the right axis includes electrical conductivity (EC, mmhos), ammonia-N (NH3-N, ppm), nitrate (ppm), total nitrogen (total N, ppm), organic matter (OM, %), and pH.

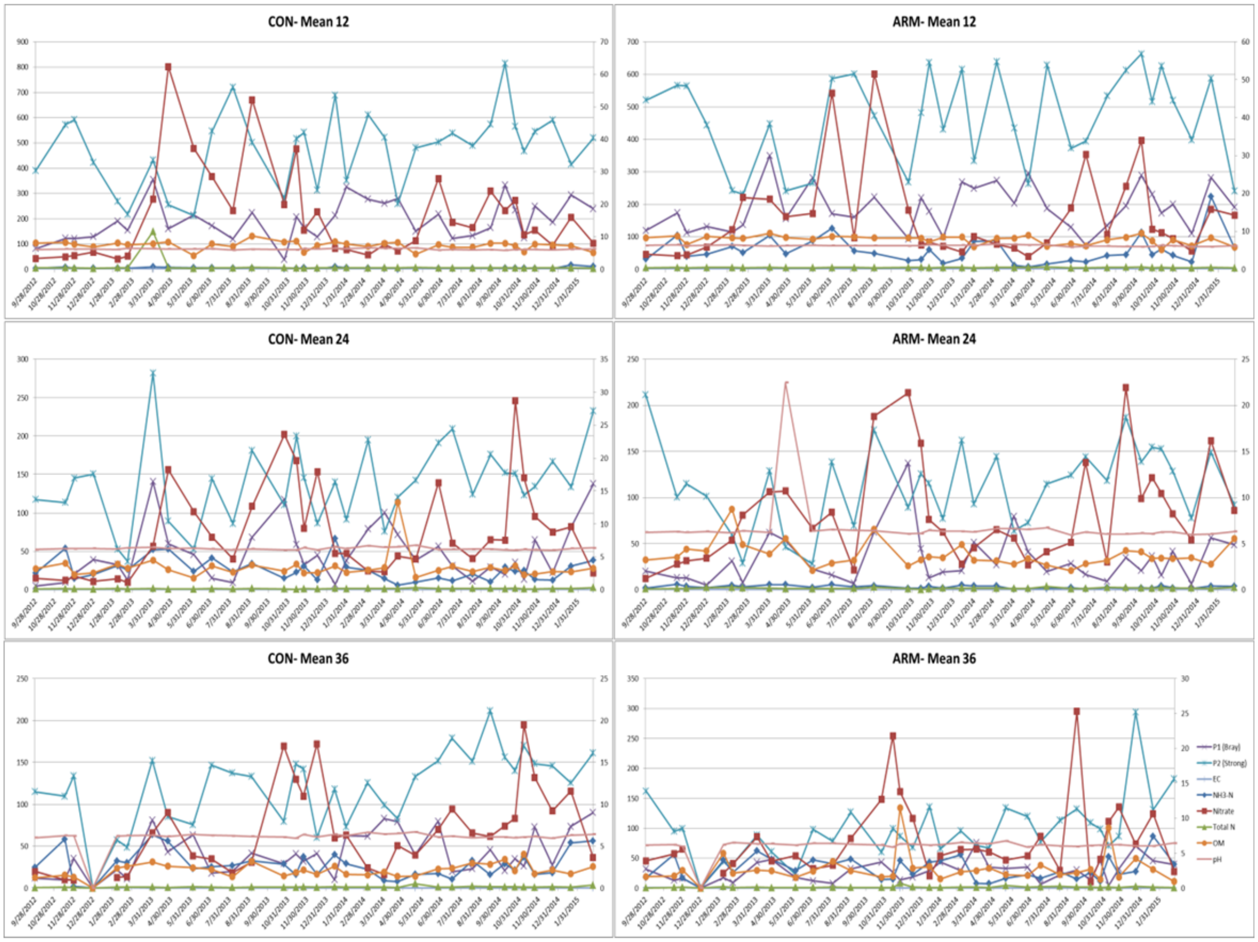


Figure 14.14. Soil nutrient "raw" data for Site C for each treatment (Con and ARM) and soil depth (12 = 12 inch, 24 = 24 inch, 36 = 36 inch). Data presented on the left axis includes total phosphorous (bray P1and P2, ppm). Data presented on the right axis includes electrical conductivity (EC, mmhos), ammonia-N (NH_3-N, ppm), nitrate (ppm), total nitrogen (total N, ppm), organic matter (OM, %), and pH.

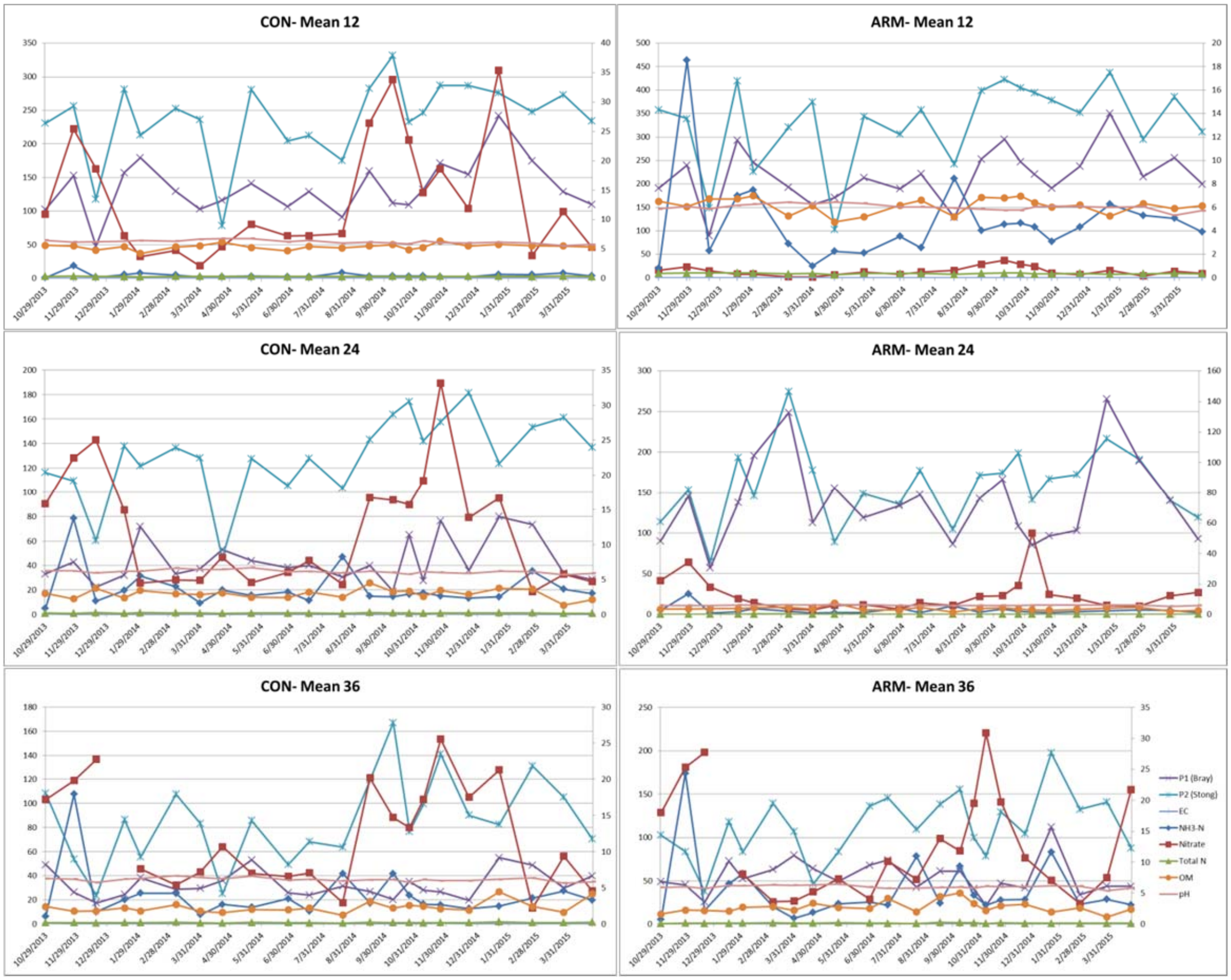


Figure 14.15. Soil nutrient "raw" data for Site D for each treatment (CON and ARM) and soil depth (12 = 12 inch, 24 = 24 inch, 36 = 36 inch). Data presented on the left axis includes total phosphorous (bray P1and P2, ppm). Data presented on the right axis includes electrical conductivity (EC, mmhos), ammonia-N (NH_3-N, ppm), nitrate (ppm), total nitrogen (total N, ppm), organic matter (OM, %), and pH.

When we looked at specific soil nutrients, such as nitrate (NO_3) (Figure 14.16), we saw an active annual pattern as nitrate moves from the upper soil layers (12 inch) to the lower layers (36 inch). Additionally, we saw that the highest soil nitrate levels present during the growing season (May-August) in the 12 inch soil layer, when the forage was actively taking it up, as could be seen from the relatively low nitrate levels in the 36 inch soil depth. For the ARM treatment, where manure was applied in January, approximately one month earlier than the first CON application, we observed a higher nitrate increase in the 12 inch soil layer in the months following application than the CON. This observation was noted in the 12 inch soil depth, but was not transferred to the 36 depth, indicating that the nitrate was being made available and taken up by the plants rather than moving through the soil profile.

The fall period (October-December) showed the soil nitrate increasing with depth indicating a movement of residual soil nitrate through the soil profile. This pattern was more pronounced in the CON treatment, which had manure applications conducted approximately one month after the final ARM treatment application into October. This indicated that in this soil type (sand), late fall manure applications may not be necessary as they had no benefit to late season forage yield

(Table 14.3) and increased the potential for soil nitrate availability and transport (see Soil Water data).

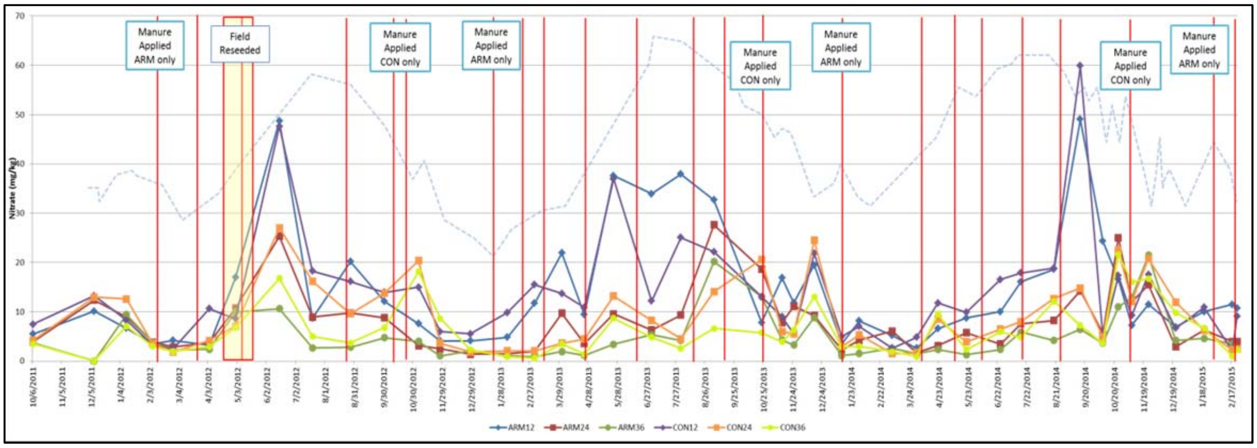


Figure 14.16. Soil nitrate "raw" data for Site B for each treatment (CON and ARM) and soil depth (12 = 12 inch, 24 = 24 inch, 36 = 36 inch). Red lines represent manure applications with applications only applied to a single treatment highlighted, all others are applied to both at the same time. Blue hashing represented the smoothed soil temperature data curve (no scale).

The soil temperature profile shown in Figure 14.16 (blue hash line) showed that the soil nitrate levels followed a very similar pattern to soil temperature highlighting the strong relationship between the two variables.

14.6.4. Soil Water

Soil water values are presented as "raw" data rather than statistically smoothed or analyzed data. This is because data for every lysimeter depth (12, 24, and 36 inch) was not able to be collected at every sampling event, as it is subject to the natural percolation and transport of water through the soil profile throughout the year. For example, some points presented are the average of all six lysimeter points when samples were available, and others just one point. In many cases, we only found water at a couple of the lysimeters at a particular depth at a sampling event rather than all six per treatment plot, and most times water was not available at all three depths, particularly the 36 inch depth. Therefore, the data presented should be interpreted by each point in context. General patterns and trends can be interpreted when combined with multiple sites and years.

14.6.4.1. Soil Water Volume

The volume of soil water collected varied greatly by site, location, depth, and season (Figure 14.17). In general, more samples were collected from the 12 inch depth than any other at Sites B and C, which had a similar soil type and profile. Site D tended to have more samples collected at the 12 inch depth, but generally had a better distribution of samples likely due to soil type and seasonal water table depth that occupationally would fill the lysimeters at the 36 inch depth.

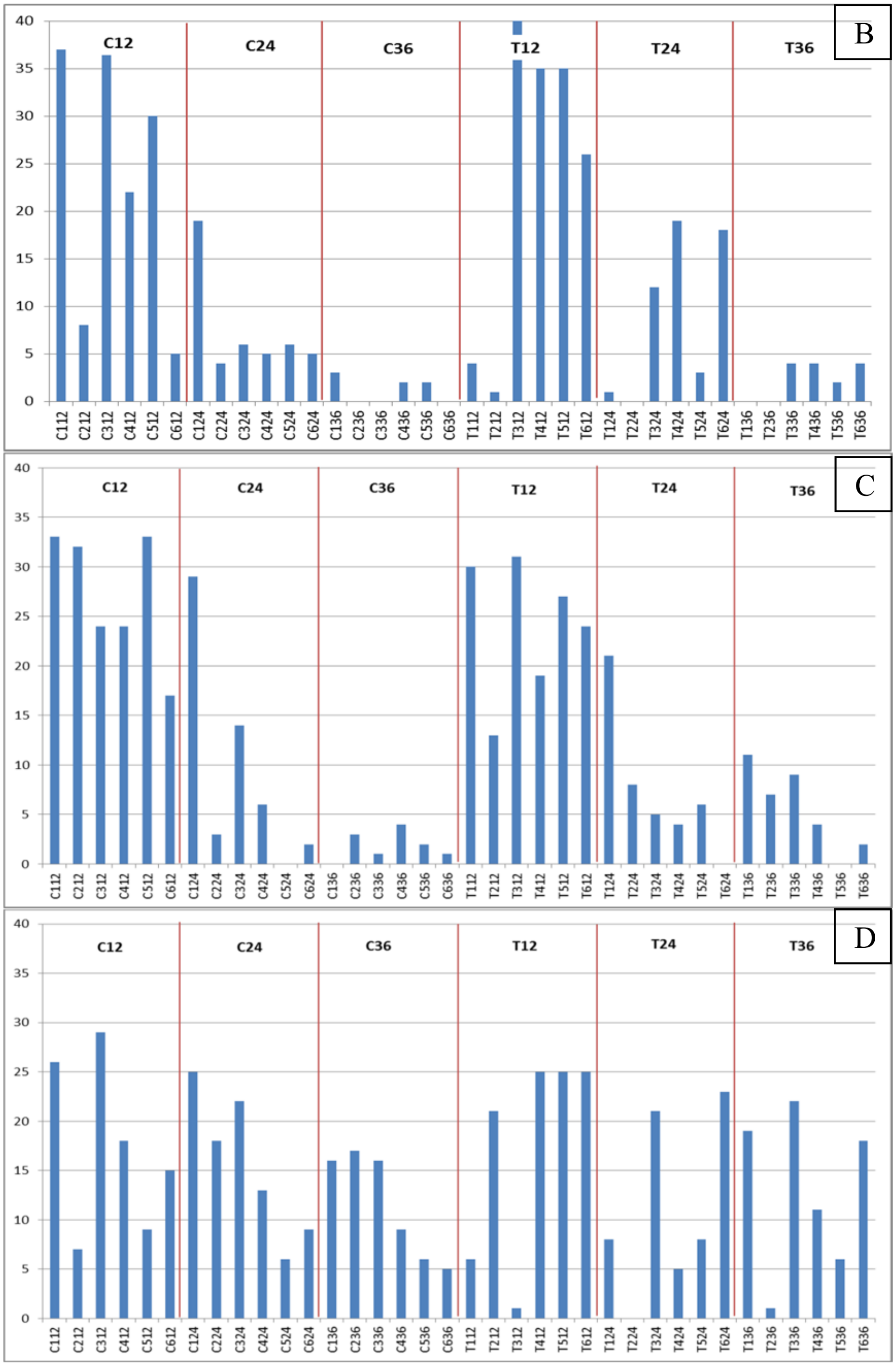


Figure 14.17. Number of soil water samples collected by site (B, C, D) plot (C or T), lysimeter number (1-6) and depth (12 = 12 inch, 24 = 24 inch, 36 = 36 inch).

14.6.4.2. Soil Water Nutrients

Soil water nutrient levels varied by site, soil type, and time of year. Since analysis of soil water nutrient levels was dependent on soil water being transported into the lysimeters, the majority of samples and points occur in the fall, particularly at the 36 inch level, which typically did not have samples until the fall (October-December). The "raw" data presented in Figures 14.18, 14.19, and 14.20, show individual spikes and erratic annual patterns. This is because any one point on a “raw” data graph can represent one or the average of six data points, depending on how many samples were collected. This means that these figures showed be viewed as informational rather than analytical.

Analysis of treatment differences at Site B (Figure 14.18) showed that on an annual average the ARM (μ = 26.9, SE = 2.6) treatment had a significantly lower nitrate value at all depths than the CON (μ = 35.5, SE = 2.4) treatment ($p = 0.02$). No significant difference was found between the two treatments for ammonia-N ($p = 0.45$) or total phosphorous ($p = 0.15$).

Figure 14.18. Site B “raw” data for soil water nutrient levels for each treatment (ARM and CON) at 12 inch (12), 24 inch (24), and 36 inch (36) depths. Data presented on the left axis includes nitrate (mg/L) and total nitrogen (total N, mg/L). Data presented on the right axis includes total phosphorous (total p, mg/L), ammonia-N (NH3, mg/L), and pH.

Analysis of treatment differences at Site C (Figure 14.19) showed that on an annual average the ARM (μ = 22.5, SE = 1.74) treatment had a lower nitrate value at all depths than the CON (μ = 24.3, SE = 1.94) treatment, but it was not significant ($p = 0.49$). No significant difference was found between the two treatments for ammonia-N ($p = 0.11$) or total phosphorous ($p = 0.98$).

Figure 14.19. Site C "raw" data for soil water nutrient levels for each treatment (ARM and CON) at 12 inch (12), 24 inch (24), and 36 inch (36) depths. Data presented on the left axis includes nitrate (mg/L) and total nitrogen (total N, mg/L). Data presented on the right axis includes total phosphorous (total p, mg/L), ammonia-N (NH3, mg/L), and pH.

Analysis of treatment differences at Site D (Figure 14.20) showed that on an annual average the ARM ($\mu = 40.5$, SE = 2.10) treatment had a lower nitrate value at all depths than the CON ($\mu = 41.0$, SE = 2.13) treatment, but it was not significant ($p = 0.85$). No significant difference was found between the two treatments for ammonia-N ($p = 0.23$); however, total phosphorous was significantly lower in the ARM treatment compared to CON ($p = 0.005$).

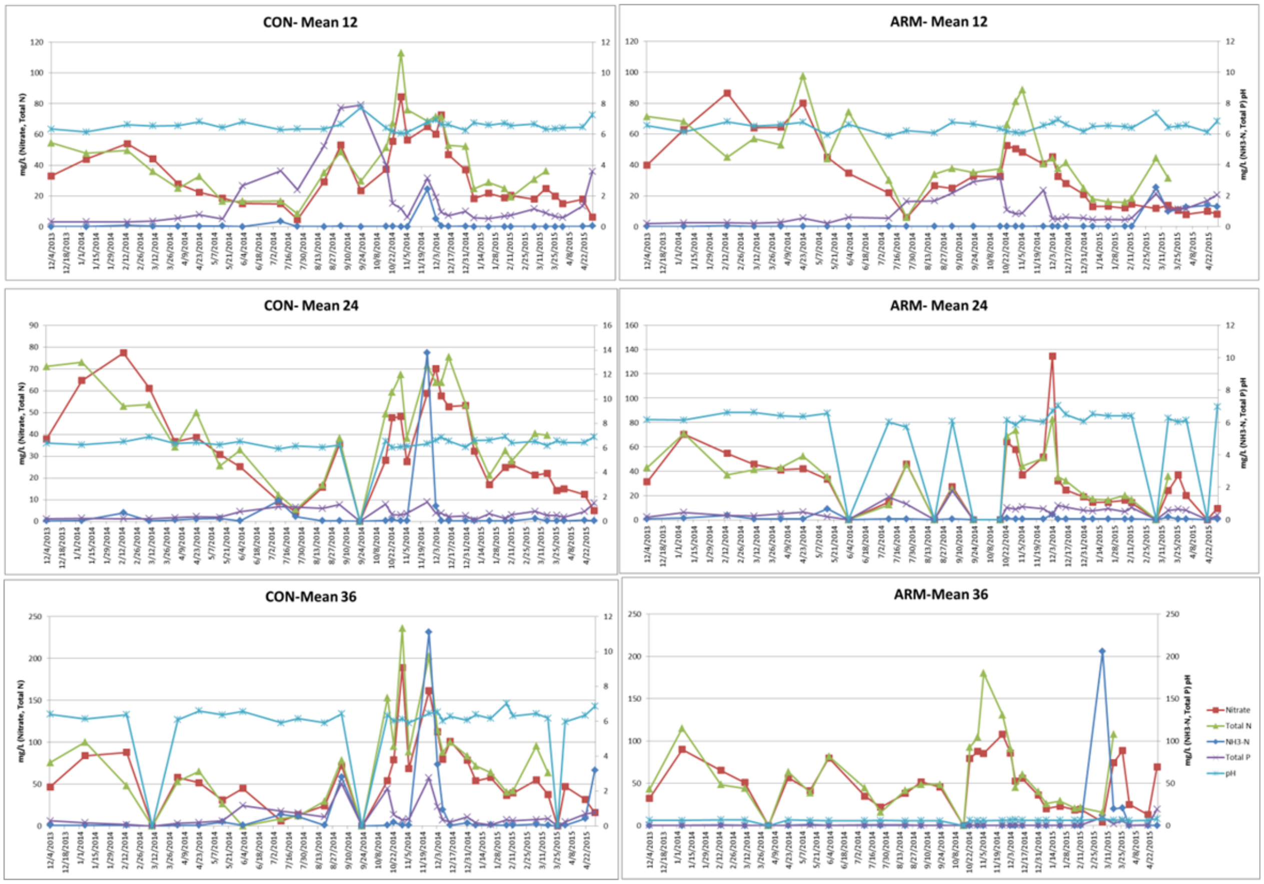
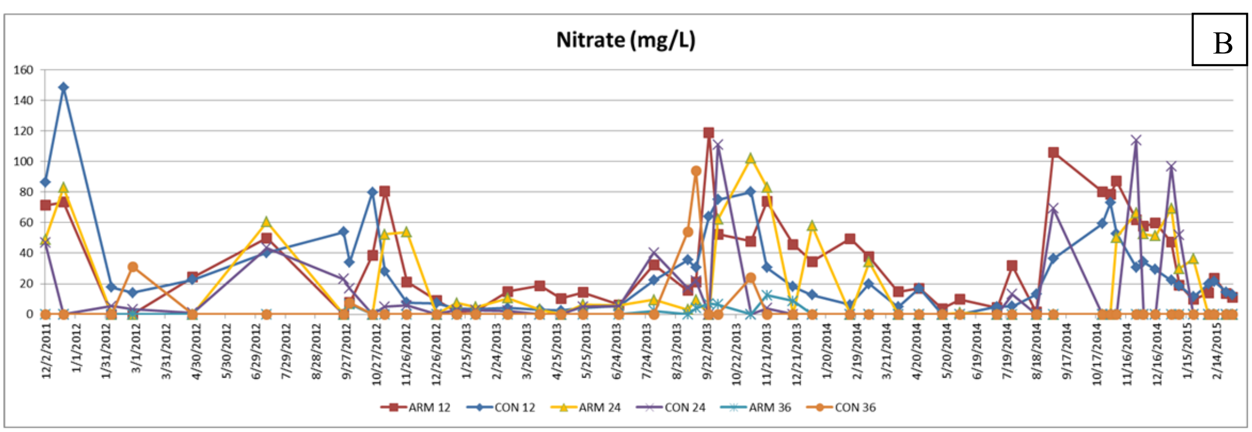


Figure 14.20. Site D "raw" data for soil water nutrient levels for each treatment (ARM and CON) at 12 inch (12), 24 inch (24), and 36 inch (36) depths. Data presented on the left axis includes nitrate (mg/L) and total nitrogen (total N, mg/L). Data presented on the right axis includes total phosphorous (total p, mg/L), ammonia-N (NH3, mg/L), and pH.

Assessment of nitrate levels in soil water (Figure 14.21), indicate that the highest concentrations occur in the fall when precipitation levels increase (see precipitation data for comparison). In general, the highest nitrate levels are seen in the 12 inch lysimeters first, followed by higher levels in the 24 and, occasionally, the 36 inch levels. Water in the 36 inch lysimeters was rare, and typically occurred in early fall when soils were dry and pore spaces larger, if at all.



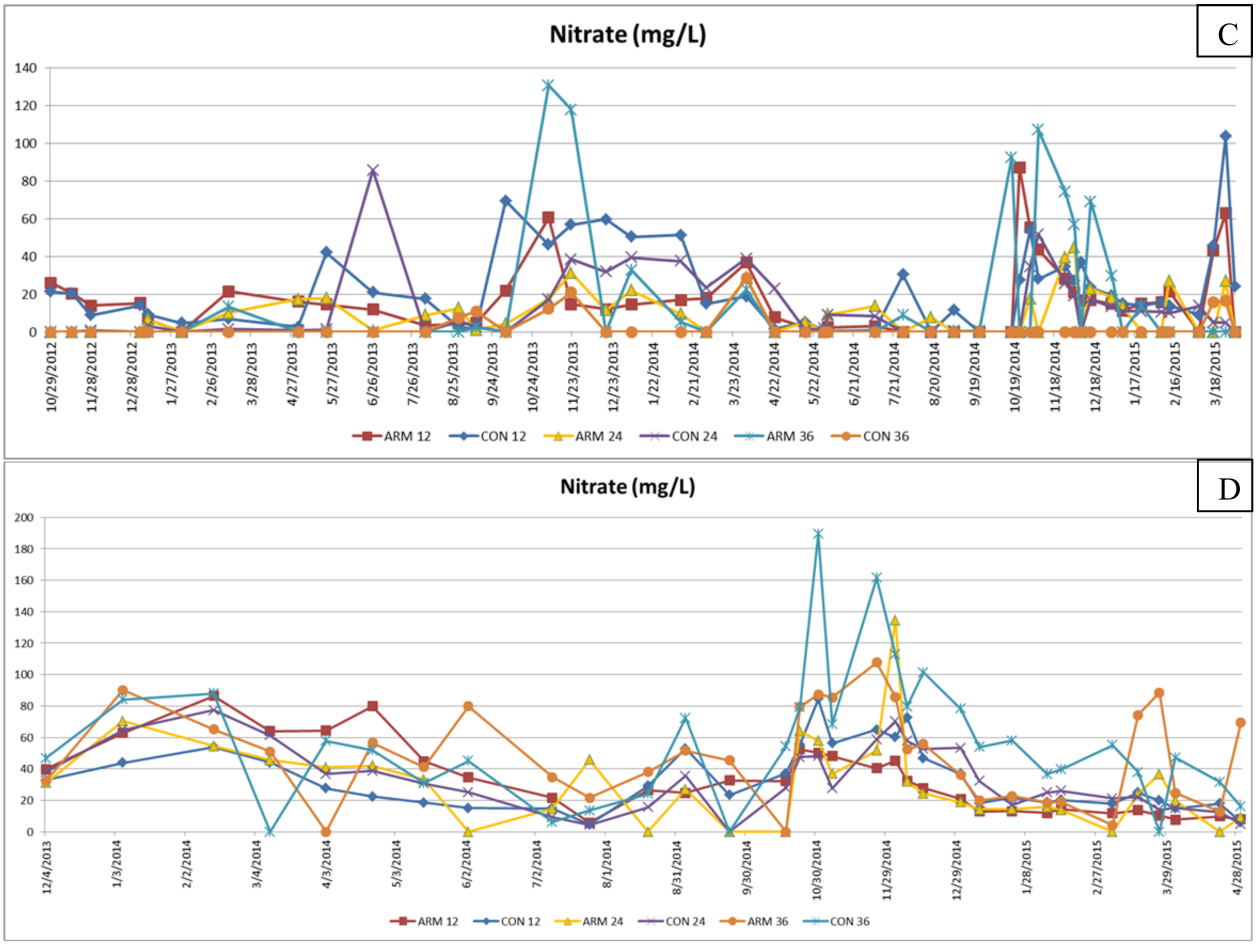


Figure 14.21. Soil water nitrate (mg/L) “raw” data for each site (B, C, and D) treatment (ARM and CON), and depth (12 = 12 inch, 24 = 24 inch, 36 = 36 inch).

The one exception to the pattern of fall spikes in Figure 14.21 was in early summer (June) of 2012 at Site B. This was due to a field renovation where the existing grass field was sprayed, tilled up, and replanted. This is a common practice throughout the County on grass fields that are in need of replanting due to decrease in forage production or field damage. We were able to observe the increased nitrate release that came with irrigation to the field (precipitation was low at that time of year, but irrigation acts the same as a rain event). This was because earlier manure applications were becoming nitrate available, the field was bare, and there was no established vegetative root base to take up the nitrate. The nitrate levels were only seen down to the 24 inch level in this situation.

The soil water nitrate levels at site C were more expected, with high fall levels and the occasional high values outside of fall. Showing “raw” data in these graphs can be misinterpreted as a single value is often times a product of lack of averages, rather than an example of the norm.

The soil water nitrate levels at Site D were very different than B and C due to the soil type. The fall spike in nitrate is still seen, but annual levels tend to be higher in general.

Comparison of depth within treatment by site revealed that the nitrate concentrations at the three depths were different and that each site displayed a different pattern of annual nitrate levels by depth (Table 14.7). At sites B and C, the ARM treatment showed higher annual average nitrate levels in the 36 inch depth, while the CON treatment had lower values at 36 inches. Site D, however, showed that the ARM and CON treatments had the same pattern with the 36 inch depth having the highest values, followed by the 24 inch, and 12 inch with the lowest values. Treatments at Site D were not significantly different from each other ($p = 0.49$).

Table 14.7. Annual nitrate sample number (n), mean, variance (var), and significance (*p*-value) for each treatment by site and depth.

Site	Treatment	Depth	n	Mean	Var	*p*-value (α=0.05)
B	ARM	12	117	23.87	725.00	0.13
	ARM	24	35	35.02	2082.95	
	ARM	36	6	39.91	1585.44	
	CON	12	144	38.27	1330.23	0.02
	CON	24	53	32.99	954.90	
	CON	36	11	8.55	64.47	
C	ARM	12	137	20.01	391.17	8.0×10^{-5}
	ARM	24	39	18.05	162.32	
	ARM	36	28	40.98	2009.42	
	CON	12	157	26.80	1007.04	0.11
	CON	24	52	19.12	373.11	
	CON	36	11	13.60	66.29	
D	ARM	12	102	35.38	739.98	0.01
	ARM	24	64	37.77	1046.99	
	ARM	36	79	49.29	1458.08	
	CON	12	104	34.28	506.32	4.9 x 10-5
	CON	24	97	34.56	538.29	
	CON	36	75	50.65	1182.08	

However, due to the fact that very few samples were collected at the 36 inch depth, and that they tended to be during the times of year with the highest nitrate levels leached (fall), these data may not give an accurate overall treatment comparison. It is more appropriate to assess the data by season. This analysis was done for Site C only as an example (Table 14.8). For the ARM treatment, all depths were significantly different by season and fall had the highest nitrate values between seasons. For the CON treatment, only the 12 inch depth showed significantly different values between seasons, likely due to the small number of samples for the 24 and 36 inch depths. In all cases, the summer soil water nitrate values were the lowest, compared to the soil levels, which are the highest during the summer indicating good plant uptake and/or low mobility in the soil profile. For all samples, the variance was high indicting that there is a lot of variability in the samples, which is potentially an effect of the variation in lysimeter location and collection efficiency.

Table 14.8. Soil water nitrate levels at Site C by treatment and depth with sample number (n), mean, variance (var), and p-value presented

Treatment	Depth	Season	n	Mean	Var	*p*-value (α=0.05)
ARM	12	Fall	51	28.92	558.56	$1.60x10^{-05}$
		Winter	46	18.89	197.22	
		Spring	25	13.63	303.97	
		Summer	15	3.81	2.81	
	24	Fall	14	27.19	198.37	0.004
		Winter	11	14.98	88.55	
		Spring	7	13.30	81.86	
		Summer	7	9.36	41.98	
	36	Fall	11	83.97	1669.90	$2.12x10^{-05}$
		Winter	8	15.72	362.73	
		Spring	3	22.52	252.21	
		Summer	6	5.05	60.77	
CON	12	Fall	60	38.88	860.76	0.0002
		Winter	54	25.55	1261.70	
		Spring	26	14.04	690.85	
		Summer	17	7.65	178.88	
	24	Fall	18	25.58	300.67	0.128
		Winter	18	13.75	200.16	
		Spring	12	22.03	761.97	
		Summer	4	5.56	8.52	
	36	Fall	4	16.53	27.62	0.457
		Winter	2	16.11	0.26	
		Spring	2	15.52	341.39	
		Summer	3	6.74	21.57	

Phosphorous levels, in general, in all three lysimeter depths tended to be very low compared to soil total P values (Figure 14.22). The spring-summer event observed 2013 at Site B was likely due to a field renovation discussed above in which the soil was tilled up and under to a depth of 12 inches. Because of the soil tillage activity, phosphorous was mechanically moved through the soil profile and made available for a short term movement down to the 24 and 36 inch lysimeters after precipitation events. In this case, CON and ARM had similar spikes during the fall of 2012 and early winter 2013 due to tillage equalizing their field effect. We never saw this event in subsequent years, indicating that soil disturbance had an effect on phosphorous transport to deeper soil layers. The elevated phosphorous levels at site C at the start of the project in early 2013 could have been due to the soil disturbance the occurred during lysimeter installation the previous fall.

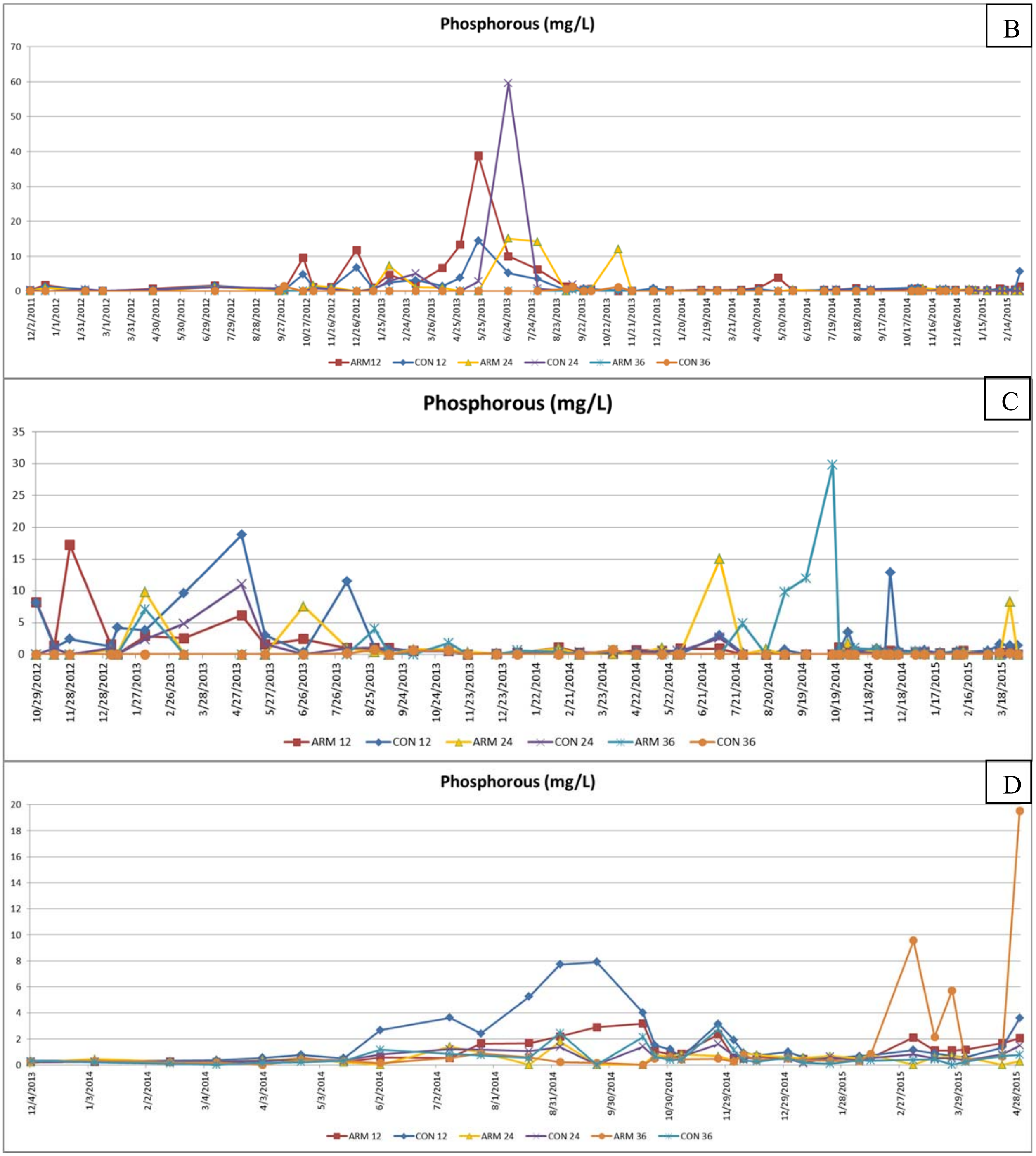


Figure 14.22. Soil water total phosphorous (mg/L) “raw” data for each site (B, C, and D) treatment (ARM and CON), and depth (12 = 12 inch, 24 = 24 inch, 36 = 36 inch).

14.6.5. Surface Water

Surface water was measured at site D only, as no other site had adjacent surface water. Fecal coliform was measured as an indicator of potential manure influence into the stream (Figure 14.23), phosphorous as an indicator of agricultural sediment from the field surface (Figure 14.24), and anomia-N an indicator of recent manure influence (Figure 14.25). Because of the method of sampling (grab, not continuous), often times the downstream sample was lower than the upstream sample. In the case of ammonia, the upstream value was typically higher than downstream, indicating that there was potential influencing sources upstream of the field site (Figure 14.25). This would indicate that the stream adjacent to field was a sink for pathogens or nutrients (Figure 14.24). More likely, the effect of dilution or sample variability in the stream water parcel collected is the cause. Either way, results of stream monitoring were inconclusive ($p > 0.05$).

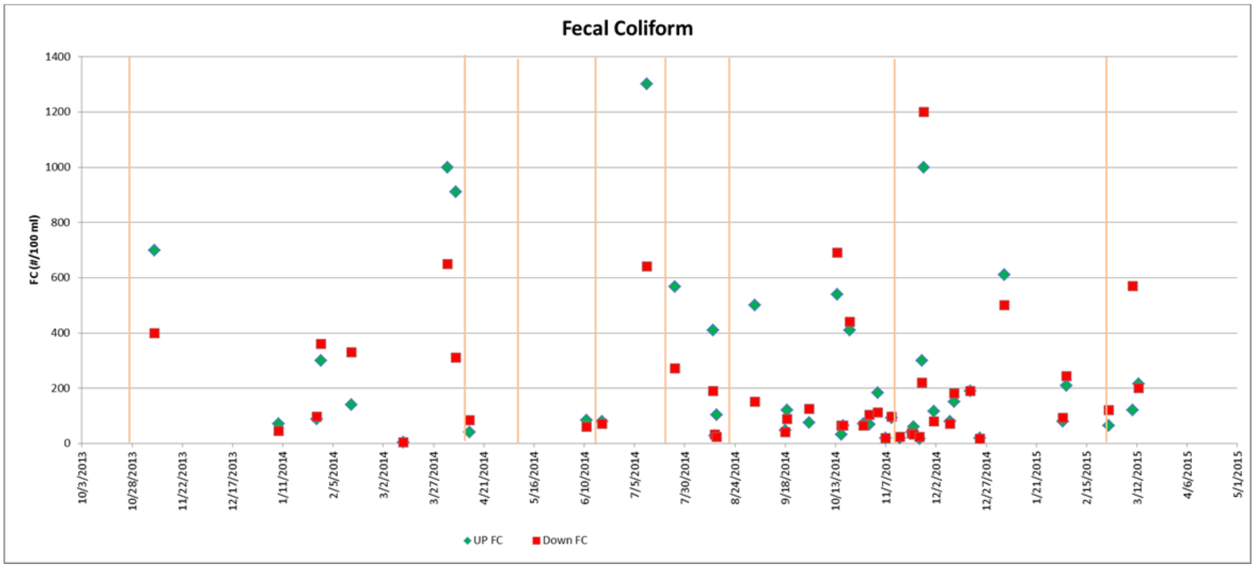


Figure 14.23. Fecal coliform (#/100 ml) measures at Site D. Green points are upstream measures, red points are downstream measures, orange lines manure application events.

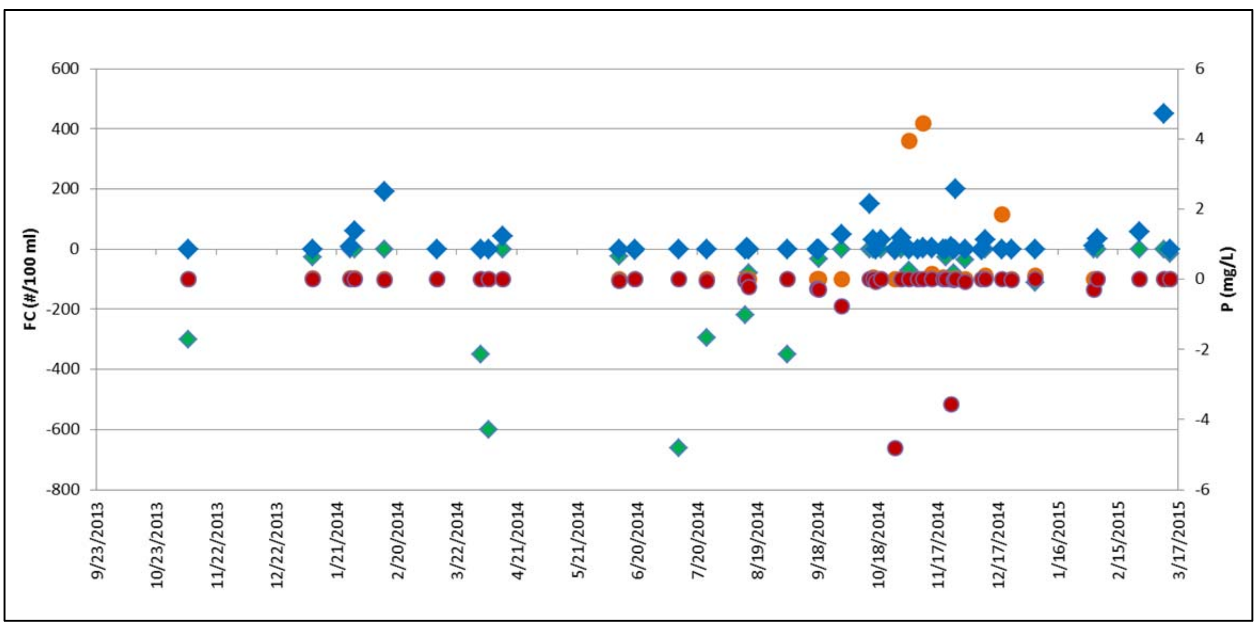


Figure 14.24. Relative difference in upstream and downstream phosphorous (red = negative difference; orange = zero to positive difference) and fecal coliform (FC) (green = negative difference; blue = zero to positive difference). Negative difference = the downstream value was less than the upstream value; zero difference = the upstream and downstream values were the same; positive difference = the downstream value was greater than the upstream value.

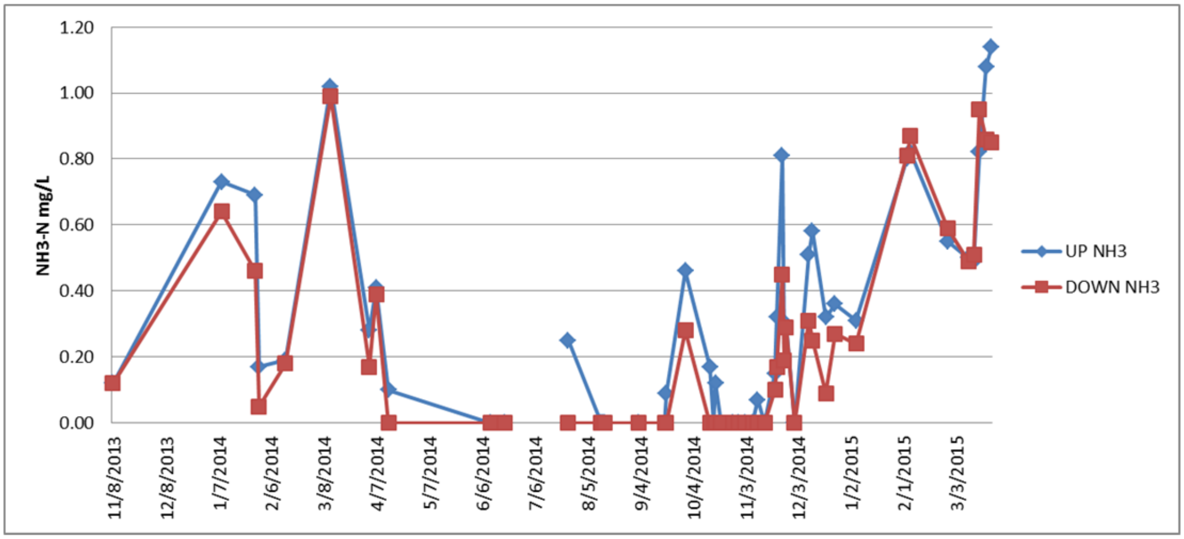


Figure 14.25. Surface water ammonia-N levels at upstream (blue) and downstream (red) sampling locations.

14.6.6. Precipitation

The daily, monthly, and annual precipitation quantities and patterns were important to understand for each project site area, Ten Mile and Clearbrook, to determine manure application timing events. They were also important in the understanding of soil saturation timing, leaching rates, runoff potential, and water table flux.

The annual precipitation curve provided a general understanding of when the major precipitation periods, or wet seasons occurred, compared to the dry months (Figure 14.26). This information was used to determine when the manure application setback distances should move from 80 to 40 to 10 feet. It also provided the curve from which examples and demonstrations were created in outreach materials.

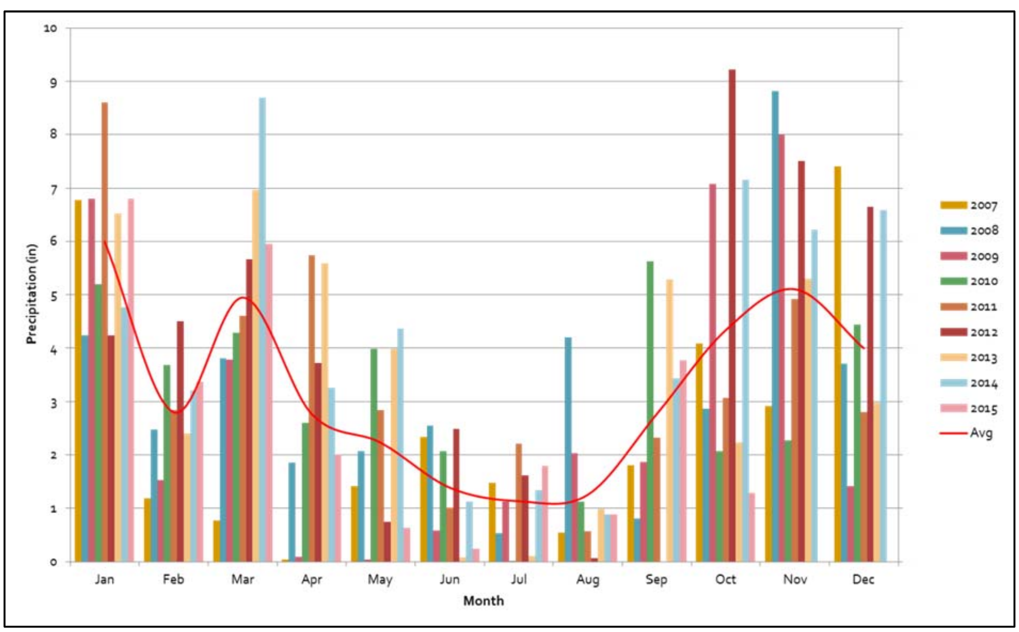


Figure 14.26. Monthly precipitation amounts in inches for Lynden, WA from 2007-2015. The smoothed annual average is shown in a red line.

Knowing the monthly totals of rain by year helped determine if it was a wetter or dryer than normal year and how that effected nutrient transport and manure application timing (Table 14.9, Table 14.10). Additionally, analysis of the amount of precipitation that fell during the storage period (October-March) was helpful to assess the change from year-to-year as a discussion point with producers and a predictor of application timing needs. Lastly, comparison of the annual and monthly rainfall at the two project areas was helpful in overall predictions and analysis of data. The annual precipitation totals for years 2011-2014 were not significantly different from each other at Ten Mile ($p = 0.95$) nor Clearbrook ($p = 0.92$).

Table 14.9. Total precipitation amount in inches by month, year, and storage season (October –March) for years 2010-2015 for the Ten Mile station location

TM	**Annual Precipitation (in)**					
Month	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Jan		8.10	3.76	5.30	3.13	5.48
Feb		2.80	4.01	2.47	2.84	2.60
Mar		3.95	5.67	3.96	6.98	5.14
Apr		5.48	4.00	4.85	3.25	1.96
May		4.23	2.04	2.86	4.41	0.57
Jun		0.81	3.21	1.97	0.82	
Jul		1.74	1.98	0.04	1.23	
Aug		0.53	0.04	1.64	0.91	
Sep		1.09	0.13	3.72	2.97	
Oct	2.31	2.85	8.02	2.30	5.97	
Nov	3.24	4.99	4.79	6.29	5.00	
Dec	5.77	2.32	5.22	3.37	5.96	
Total (year)	***11.32****	***38.89***	***42.87***	***38.77***	***43.47***	***15.75****
Storage Period	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2015-16**
Total (Oct-Mar)	*NA*	*26.17*	*23.60*	*29.76*	*24.91*	*30.15*

*This value does not represent a full year of precipitation.

Table 14.10. Total precipitation amount in inches by month, year, and storage season (October –March) for years 2010-2015 for the Clearbrook station location

CB	**Annual Precipitation (in)**					
Month	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Jan		12.20	5.30	6.30	4.36	7.17
Feb		3.50	5.68	2.96	3.09	4.51
Mar		5.21	6.65	7.10	10.23	7.16
Apr		6.44	6.13	5.93	4.38	2.35
May		5.80	2.87	3.79	5.26	0.75
Jun		1.07	4.80	2.78	1.96	
Jul		2.19	1.88	0.00	1.81	
Aug		0.66	0.03	1.44	0.73	
Sep		2.66	0.25	5.70	3.82	

Oct	3.28	3.80	10.47	2.47	7.71	
Nov	6.16	5.89	7.05	7.72	7.50	
Dec	7.72	3.68	6.83	4.40	8.41	
Total (year)	***17.16****	***53.10***	***57.93***	***50.58***	***59.27***	***21.94****
Storage Period	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2015-16**
Total (Oct-Mar)	*NA*	*38.07*	*31.00*	*40.70*	*32.27*	*42.47*

*This value does not represent a full year of precipitation.

Analysis of the total number of annual rain events (event = 24 hours from 0800 to 0759) and the amplitude of those events indicated that there are more 24 hour events under 0.25 inches of rain and few over 1.00 inches of rain at both weather stations assessed (Table 14.11). The Ten Mile and Clearbrook stations had a similar number of annual rain events, but the Clearbrook station had more large events recorded, particularly over 1.00 inch. This indicates that that area had a greater potential for precipitation induced runoff events.

Table 14.11. Total number of precipitation events annually, and number of days the precipitation was over 0.25, 0.50, and 1.0 inches for the Ten Mile and Clearbrook weather station locations

	Total # rain days per year	**# Days over *x* inches of precip**		
		>0.25	**>0.5**	**>1.0**
Ten Mile				
2015*	72	17	9	3
2014	160	65	33	6
2013	169	55	27	3
2012	168	67	27	3
2011	169	58	20	5
2010*	50	15	6	1
Clearbrook				
2015*	69	26	16	5
2014	159	88	47	17
2013	153	72	37	10
2012	189	89	40	8
2011	182	81	33	9
2010*	54	20	11	3

*This value does not represent a full year of precipitation.

Rainfall intensity is important when considering manure application timing and potential runoff events, but the total number of days is just as important when considering the effect it has on soil moisture and subsequent manure application limitations. Soil needs time to dry out to a level where it can receive additional moisture in the form of manure before application, otherwise a runoff event is possible. This consideration is taken into account by asking users to assess soil moisture, in conjunction with precipitation, in the ARM worksheet.

15. CONCLUSION

This report was intended to present the information and findings of the project, as well as connect some of the parameters together to start to understand the complexity of the system. While this is not a peer reviewed publication and should not be treated as such, the information presented will be used to create more thorough, complex inspections of individual parameters and interactions that will form into peer reviewed publications.

Overall, we found that improved timing of manure application based on soil type, current field conditions, and real-time precipitation events, had a positive effect of the leaching of nutrients such as nitrate through the soil profile, and may also limit runoff events, particularly in the fall and spring months. By using the tools developed including field risk mapping, Manure Spreading Advisory, ARM Worksheet, and manure application setback distances, a manure applicator can make an informed decision that will better protect surface and groundwater resources.

This project produced a vast array of interconnected data that provides information and feedback to both better understand the connectedness of manure application and the natural system it interacts with, but also how to build effective tools to assist users in making better decisions to protect surface and groundwater resources. The ARM tools produced have given producers a tool and process to better evaluate manure application timing. The results of this study support the concepts and implementation of the ARM system, particularly under conditions presented in this study. We have extrapolated the data to other conditions and situations not actually tested in this study with the confidence that they will be successful based on the information available. We have to note that while the tools and information created as part of this project have been shown to be effective under ideal use, it is up to the individual user to properly implement the guidance in order to have the same successful outcome.

The outcome of this project was successful in providing a better look into the manure-natural system. It answered many questions, as well as raised new ones for exploration. The ARM tools will continue to be improved and updated as new information and technologies become available. The ARM tools are also being adapted to other regions of the US and Canada for use.

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